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Entity Modeling and Immersive Decision Environments

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14. ABSTRACT
The overall purpose of the work was to identify candidate approaches to solve Distributed Mission Operations (DMO) Modeling and Simulation (M&S) deficiencies in the optimal presentation of information to decision makers in multi-modal immersive environments. This report covers five main research and development areas that were completed towards this goal. Those areas included: Robust Immersive Decision Environments Research (RIDER), Rehearsal Enabling Simulation Technologies (REST), Entity Modeling and Full Spectrum Threat Simulation, Audio Integration/Demonstrations, and Ultra-High Resolution Deployable Projector Components for Simulation (this work centered on the Immersive Display Evaluation and Assessment Study or IDEAS).

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1.0 SUMMARY

Task Order 0037, under the Warfighter Readiness Science & Technology Program (WRSTP) contract, identified candidate approaches to solve Distributed Mission Operations (DMO) Modeling and Simulation (M&S) deficiencies in the optimal presentation of information to decision makers in multi-modal immersive environments. The scope of the task included developing and validating system dynamics decision models and conducting human factors experimentation on optimization of immersive environments for a wide range of training applications. The tasking also included identification of methods for quickly and accurately modeling, rendering and displaying physics-based dynamic three-dimensional (3D) weather, weapons effects, other special effects, and associated visual and sensor impacts in a standard open format for sharing between networked DMO training and rehearsal scenarios and locations. These efforts developed approaches to train, and prepare warfighters in immersive environments with dynamically shared common weather, weapons, visual and sensor effects (an identified capability gap), thereby improving warfighter anticipation, competencies, and associated mission performance. The WRSTP team has presented the research results at a number of conferences and reported them in numerous journals.

During this tasking the WRSTP team also developed physics-based representations of directed energy weapons and their effects on sensors and vision and generated methods of integrating these effects into enhanced visual displays. The team also demonstrated 6-degrees of freedom (6DoF) aero models in a real-time or near real-time training network, and developed rule sets for functional handoff of aero models from one level of complexity to another to maximize computational capability. The above tasking benefits the United States Air Force (USAF) because it enables warfighters to conduct extremely realistic training at real time or near real time against complex threats. Physics-based representations provide accurate Computer Generated Force (CGF) maneuvering for air combat training in networked simulation, maximizing the utility of next-generation simulation displays, eliminating random engagements in training, and upgrade quickly if new threats emerge.

As the WRSTP team continued to execute this task order, we identified several additional research areas, which expanded the scope of work. These included Entity Modeling and Full Spectrum Threat Simulation (EMTS), Audio Integration Demonstration, and High Resolution Deployable Projector Components for Simulation.

This final report summarizes work completed under Task Order 0037 on the WRSTP, contract number FA8650-05-D-6502 for the Warfighter Readiness Research Division of the Air Force Research Laboratory (AFRL) (711 HPW/RHA).

2.0 RESEARCH AREAS

This section details the following research areas: Robust Immersive Decision Environments Research (RIDER), Rehearsal Enabling Simulation Technologies (REST), Entity Modeling and Full Spectrum Threat Simulation, Audio Integration/Demonstrations, and Ultra-High Resolution Deployable Projector Components for Simulation.

2.1 Robust Immersive Decision Environments Research

The RIDER research effort identified methods and fidelity requirements for training in immersive decision-making environments. The WRSTP team investigated three different types of decision-making models: decision priming, Recognition Primed Decisions Model (RPD), and implicit learning for intuitive decision making. Decision priming refers to a situation in which multiple sources of information that are presented to an observer are distributed in time, and the observer is asked to make a speeded decision as to whether to execute one type of response or another. Decision priming occurs when initial information suggests the expectation that a given decision is appropriate, and that expectation speeds up decision-making. The RPD model (Patterson, Pierce, Bell, Andrews, and Winterbottom , 2009; Patterson, Fournier, Pierce, Winterbottom, and Tripp, 2009; Patterson, Fournier, Pierce, Winterbottom, and Tripp, 2009) states that decision making in naturalistic contexts entails a situational pattern-recognition process, which if subsequent expectancies are confirmed, lead the decision maker to render a decision to engage in a given course of action.

The implicit learning effort began by exploring whether findings from the basic literature (Reber, 1967; Reber, 1989) for implicit statistical learning of static information can be replicated by employing simulated tactical scenarios in an immersive environment where information will be dynamic, more realistic and therefore more complex. Implicit statistical learning refers to the learning of statistical regularities in a pattern of stimulation without a deliberate conscious effort (Patterson, Pierce, Bell, and Klein, 2009; Patterson, 2010). It has been suggested that this is a means by which the foundation for the intuitive pattern-recognition is developed. This intuitive process greatly aids in robust decision making in dynamic environments where information is limited and time constraints exist. The possibility that implicit learning can lead to successful intuitive decision making made it likely that the development of such decision making could be studied by inducing implicit learning with high-fidelity environmental cues and patterns.

Through a series of experiments, various training methods and requirements were explored. These include how best to design and present information for implicit learning within a training environment (Patterson, Pierce, Boydstun, Park, Shannan, and Tripp, 2010; Patterson, Pierce, Boydstun, Park, Shannan, and Tripp, 2010) determining how diversity and organization of the training stimuli affect learning and whether this information can be transferred to another domain (Winterbottom, Patterson, Fournier, Pierce, Williams, Amann, 2009), how algorithmic complexity (length and complexity of the algorithm) affects the acquisition of information and how implicitly learned information is retained over time (Boydstun, Patterson, Pierce, Park, and Shannan, 2010; Boydstun, Patterson, Pierce, Park, and Tripp, 2011). A paradigm was developed to explore, and ultimately did demonstrate, the unconscious and non-volitional acquisition of information relating to the patterns of image sequences in a flight-simulated environment. The enhanced understanding of robust decision-making processes, which resulted from this work, will help identify user cuing needs and technology requirements to optimally train decision makers in multi-modal immersive environments. The effort will provide to current and future warfighters the capability to experience, train, and rehearse in immersive environments with cues necessary for robust decision making.

2.1.1 Methods, Assumptions, and Procedures

For the intuitive decision making experiments, we investigated whether naturalistic, intuitive (pattern-recognition-based) decision making can be developed via implicit statistical learning in

a simulated real-world environment. The environment was composed of object sequences (e.g., vehicle, house) placed on terrain imagery presented in perspective view, and the order of the objects in the sequences was defined by different paths taken through a finite-state algorithm. Images and the terrain were generated using MetaVR Virtual Reality Scene Generator (VRSG) and were presented on a 50” display with a resolution of 1920 x 1080. The environment was presented dynamically which induced a sense of simulated locomotion through the scene as the participants viewed the object sequences. The sequences were either generated randomly or via a statistical algorithm. During training, subjects passively viewed a sample of target sequences from the total number of sequences produced by the algorithm. During test, subjects viewed another sample of the remaining target sequences randomized with an equal number of randomly generated sequences, and were asked to make intuitive decisions about whether the sequence presented represented one from the algorithm or was random.

2.1.2 Results and Discussion

The principal results of the decision making research effort shows that passive exposure to spatio-temporal patterns in a simulated real-world environment can induce a level of implicit learning that is more than sufficient for creating a foundation for intuitive (pattern-recognition-based) decision making. This suggests implicit learning, along with working memory, does play a role in the development of intuitive decision making and implicit learning can be a vehicle for developing intuitive decision making in a simulated real-world environment.

In our early experiments, we investigated the acquisition of intuitive decision making via the process of implicit learning. Participants passively viewed structured sequences of objects or letter strings presented either on a dynamic terrain seen in perspective view or on a static flat display. We also had participants memorize structured strings of letters presented on a static flat display. Following training, participants were tested for implicit learning by making intuitive judgments of novel structured sequences versus random sequences. The results of this effort showed that implicit learning occurred easily across all conditions and there was no significant performance advantage to one viewing condition over another. This study has implications for the training of intuitive decision making insofar as it demonstrates that cues can be passively and effectively acquired from exposure to different artificial displays.

As a follow-up, we investigated the effects of articulatory suppression, training block size, and complexity within the immersive implicit-learning paradigm. These results showed articulatory suppression and pattern complexity impaired decision making, but block size did not. Performing an articulatory suppression task degraded decision making because the task occupied explicit cognitive resources, which are likely linked to working memory. Training-sequence length interacted with algorithmic complexity such that performance was best when training-sequence length was long and the algorithm was simple, and when training-sequence length was short and the algorithm was complex. Thus, it was determined that when training intuitive decision making, training-sequence length should be matched to algorithmic complexity.

Implicit learning, which entails the largely unconscious learning of dynamic statistical patterns and features, is a ubiquitous, robust phenomenon that likely occurs in most, if not all, tasks in which individuals engage throughout their lives. Thus, implicit learning is likely to occur, in parallel fashion, when individuals develop expertise in a given content domain. This invites the speculation that the enhancement of implicit learning may assist in the acquisition, retention, and transfer of expertise.

2.2 Rehearsal Enabling Simulation Technologies

REST is an AFRL program actively engaged to improve DMO simulator database development processes. REST established a prototype DMO database generation and modification system to aid evaluation of, and identify improvements to, the end-to-end DMO database generation process supporting all DMO players. This effort comprised the development of the database generation system as well as the demonstration of databases that were generated using the REST system.

The REST program investigates novel source data and software tools to improve the DMO database generation process. It also participates in the development of database standards to improve database reusability, fidelity, and correlation. The REST database generation system consists of software tools and processes to be transitioned to ACC for the rapid development of high fidelity visual and sensor simulator databases for use in DMO training and rehearsal. These databases will be stored in standard industry data formats which can be easily shared and reused by all DMO participants.

2.2.1 Methods, Assumptions, and Procedures

Using the general REST DMO database generation process, the REST team was able to build databases and orchestrate the building of other databases in different runtime image generator (IG) formats with a high degree of correlation by building each using the same source dataset package. A variety of commercial data manipulation software tools which were able to ingest the same data formats (Digital Terrain Elevation Data [DTED], Geospatial Tagged Imagery File Format [GeoTIFF], Environmental Systems Research Institute [ESRI] Shape, and Presagis OpenFlight) were used.

REST's source data is stored in Air Force Common Dataset (AFCD) formats enabling ingestion by most or all database generation toolsets. Elevation data is stored in DTED format, and ground imagery is in GeoTIFF. Presagis TerraVista, TerraSim's TerraTools, ESRI ArcGIS, and MetaVR's Metadesic Compiler can read these formats to generate terrain databases. For cultural features, we used models in Presagis' OpenFlight, which is easily converted into most other runtime formats. To describe the placement of these models we used ESRI Shape files. A shape file can be viewed and edited in ArcGIS, and can be used to place models in databases created by TerraVista or TerraTools. MetaVR TerrainTools can convert shape files into its culture file format, which can be used to place models in a MetaVR database. For some of the REST demonstrations, we used DTED Level 2 and 5 meter and 60 centimeter imagery from REST's Western Ranges Dataset (WRDS), 1m imagery provided by the USAF's B-1 training system program, building models provided by the UK Ministry of Defense (MoD), and buildings and vehicle models from various other sources, most notably the Army's Synthetic Environment (SE) Core program.

2.2.2 Results and Discussion

In order to demonstrate the capabilities of the REST system developed under this effort, multiple databases were developed under a requirement for the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC) 2010. The requirement involved building a scenario in which friendly forces would deploy from a forward operating base (FOB) and escort a United Nations (UN) convoy to a village, where they would be ambushed by ground forces and a

helicopter. The REST team built correlated terrain databases for each of the five simulators involved that collectively resembled the Middle East and included an FOB and a village.

The team encountered unanticipated problems during the course of building the databases. Many of these resulted from a lack of familiarity with the tools involved, or minor issues within the tools themselves. There also were correlation issues in the OpenFlight models resulting from using them in runtime systems not designed for this use, or from converting them into different formats. Most of these problems were solved and the solutions were documented.

Although OpenFlight is a standard format for storing 3D models, OpenFlight also has numerous methods of handling things like lighting and infrared (IR) effects. The following is a list of some of the attribute problems encountered with reusing OpenFlight models from other programs: IR polygons, nighttime texturing, level of detail, primary color of textures, buildings with footprints, and texture drawing problems.

We chose to build the MetaVR database first, because of how easy it is to place models in MetaVR and then convert the resulting culture file to a shape file that can be used to build the other databases. However, it would also be possible to create a MetaVR database using a shape file from another database. TerrainTools can convert a shape file to a culture file just as easily. Given an OpenFlight database, for example, along with the source data used to generate it and a shape file describing the placement of its cultural features; one could easily generate a correlated MetaVR database from that.

In addition, many other software tools exist which can produce similar results. Presagis TerraVista can also produce OpenFlight and VBS2 terrain databases. Global Mapper can be used to edit and reproject imagery. MetaVR databases can be built without the use of ArcGIS and TerrainTools, but they help a great deal in visualizing and selecting the data to be used in generating a database. TerrainTools' ability to convert shape files to and from culture files also makes generating correlated databases a great deal easier.

The demonstration databases built and provided for I/ITSEC 2010 represents only one success in the development of the REST Database generation process and generation of multiple databases using this process. The demonstration was a success and also produced some lessons learned in the creation of the databases. The lessons learned, as described above, will be integrated into future database development processes and used to further refine and standardize this process.

2.3 Entity Modeling and Full Spectrum Threat Simulation

Entity Modeling is developing modeling and simulation, physics, and computational methods to provide optimal real-time computer-generated forces interactions, and models of advanced and emerging threats, sensors, emitters, communications, and data-links. The WRSTP team developed and modified software tools such as eXpert Common Immersive Theater Environments (XCITE) to implement the use of user-defined triggers for executing tactics and scripts and operating sensors and radios.

2.3.1 Methods, Assumptions, and Procedures

Modeling highly complex entity interactions with high precision is challenging in distributed training simulations. During this effort, the team developed physics-based directed energy and other threat models, such as missiles, and integrated them into the DMO test bed. We maintained compatibility with existing simulation facilities and assessed, validated, and, documented the resulting training capabilities of the combined systems when applicable.

2.3.2 Results and Discussion

Research and development work on this effort produced numerous results as outlined in the sections below.

2.3.2.1 Missile Server

The WRSTP team integrated advanced AIM-120, 6DoF real-time or near real-time weapon models developed under a Cooperative Research and Development Agreement (CRADA) with Raytheon into DMO and live-virtual-constructive (LVC) environments for evaluation of training utility.

2.3.2.2 Directed Energy

As a standard that is currently in development, the DMO environment previously did not support Directed Energy (DE) weapons under the DIS standard. After receiving a draft of the new standard from developers at AFRL's Directed Energy Directorate, we recognized that incorporating DE weapons into XCITE was a two-part development project. We had to add the ability to send and process properly formatted DE protocol data units (PDUs) to the XCITE DISNET architecture. In addition, these weapons had to be given special processing within the XCITE core code, as they do not have the same flight and destruction physics as traditional kinetic weapons. We solved the first part by investigating the current method for sending and processing other types of messages and adapting them for these new DE-specific fields. The second part required laying out a way to fit these massless, speed of light weapons into the current weapon structures. We added new fields and exceptions in the code to handle them as well as setting aside a procedure for processing damage inflicted by DE weapons based on a simple dwell time model. After testing in multiple environments onsite, a DE-enabled version of XCITE was delivered to customers at the AFRL DE Simulation Lab at Kirtland AFB prior to the ACE10 (Advanced Concepts Event 2010) event in April 2010. Viewed by upper members of the Air Force and Pentagon, the Chief of Staff of the Air Force recognized XCITE for its involvement in the event.

The WRSTP team completed the design, coding, and integration effort that provided an automated handoff of the responsibility for computing entity damage status during a DE engagement. Previously, XCITE always computed and published damage status. The handoff gives the computation task to the L-3 Orlando Physics-Based Environment Generator (PBEG) application. Now PBEG may provide XCITE with the information it needs to publish damage status to all applications in the DMO network.

2.3.2.3 Entity Count and Processing Capacity

WRSTP engineers investigated methods to increase entity count. A method was tried which employed hyper-threading to increase the number from 185 to 205 XCITE player entities per 60 Hz frame. Continued work would prove useful because a multicore, multiprocessor computer could process high-fidelity player models at 60 Hz for up to at least 1,000 entities without experiencing frame overruns. The key is to redesign the XCITE software to make better use of threading and object oriented design. The current design is process oriented and the computers that XCITE typically runs on at the research site are underutilized when there are multiple processors available, which the XCITE routines do not use.

The WRSTP team completed a majority of the development of application software, which now provides the ability for AFRL's XCITE and Threat Instructor Operator Station (IOS) tools to function simultaneously on the same computer. Previously, the engineers, research scientists, and

instructor pilot community were required to obtain and use at least two computers to accomplish any training event that used XCITE.

2.3.2.4 Database Commonality

An earlier growth path of the Next Generation Threat System (NGTS)/XCITE research and development had used differing entity model naming conventions for each of the various security classification levels of the CGF application's databases. This difference in the names of models proved problematic when creating, reusing, merging, or sharing model data. Where possible, the structure and form of data tables and parameters should remain common despite differences in security classification level of the data. The WRSTP team have successfully modified the software functions and database for more commonality at all the security levels. Developers found that this effort cleared up several issues and errors that were inherent in the previous design.

2.3.2.5 Scenario Overlay

The training research community expressed the need for the XCITE CGF to load additional previously saved scenario data. After the user loaded an initial scenario and began the training event, they could not add further saved scenario information without clearing the currently running scenario. We developed the ability for an instructor operator to easily generate several new entities by selecting a saved file. Now the training environment can be quickly expanded to meet immediate needs without being ―trapped" in the bounds of capability of just a single scenario data file. Future growth plans should include a way to automatically script the scenario overlay function to reduce operator workload during the creation of scenarios, this ability could reduce effort needed when the operator is reusing portions of scenarios.

2.3.2.6 Jammers

The WRSTP team developed XCITE sensor/emitter models to represent advanced physic-based radar jamming systems. The CGF uses jammer emitter identification data tables to apply specific techniques to a target's radar. New algorithms developed model blinking noise, cooperative Doppler noise, and others. The CGF applies the jamming to networked training devices by publishing standard DIS packets.

The enhanced Threat IOS parses all the information received in a DIS Emission PDU. Received parameters display status to the research scientists and instructor/operators. This includes all track files and jam tracks. In a DMO network environment, the feedback provided shows which emitters are jamming which sensors and weapons, with which jamming class and technique. The enhancement benefits the provider of the training scenario because users previously did not observe accurate status for all sensor systems and sensor beams, and were not able to see or control jammer effectiveness and jammer emitter IDs.

The XCITE application to simulate towed decoys was primarily developed on a different task order. However, this TO 0037 effort included work to update the Threat IOS tool to allow the end-users to deploy and sever the decoys, visualize the devices, and control the jamming technique of the decoys.

2.3.2.7 Weapon Employment, Doctrine, and Tactics

The WRSTP team enhanced the XCITE CGF to accept and use weapon employment, doctrine, and tactics (EDT) parameters provided by instructors/operators after a training scenario commenced. Previously, users defined static values in a database and these remained constant throughout the mission or event. The operational training community desired to adjust EDT

parameters –on the fly" by easily and quickly entering or picking new values while the mission was running. Now that the CGF has been upgraded, the remaining development involves making the corresponding enhancement to the Threat IOS application. The XCITE graphical user interface (GUI) should be modified to show the user's current EDT status for a selected player entity/target entity pairing. The Threat IOS should give the option to change EDT parameters at anytime or to revert to the default values using a simple user control.

2.3.2.8 Triggers

The WRSTP team introduced the capability in the XCITE CGF to employ user-defined triggers that cause simulated entities to act and behave in a more versatile manner that may often appear more lifelike to the student/trainee. Research should continue to put triggers under the control of a user-definable script. This will vastly reduce operator workload and produce a realistic training environment.

2.3.2.9 Transfer of Control

WRSTP engineers explored methods to enable XCITE to automatically transfer control of player entities between the various CGFs in a DMO network.

2.3.2.10 NAVAIDS

WRSTP engineers developed XCITE to simulate navigational aid systems (NAVAIDS). Users can easily create, move, and delete entities. Frequency and transmitter state are user editable. The tool includes a database of known Tactical Air Navigation Systems (TACANs). Transmitter PDUs and entity state PDUs are published for all NAVAIDS that are created by or controlled internal to XCITE. Additional software development work is necessary to achieve conformance to DIS standards. The extra effort should include modifications to the XCITE network interface unit (NIU) to further develop support of the standard identification friend or foe (IFF)/air traffic control (ATC)/NAVAIDS PDU. This enhancement was not completed during the course of this task order because of limited funding for software engineering and development.

2.3.2.11 Manual Control

Scenario providers in DMO events want more manual control of constructive entities than is in the current version of AFRL's XCITE application. Research and development should continue to explore ways to give users the ability to simply select a player entity and quickly choose which systems they want to control while allowing the CGF program to continue simulating the algorithms, modes, and effects that the operator wishes to remain operating automatically and under the control of other players or scripts. WRSTP contractors recommend integrating AFRL's DIS network enhancements to the XPlane tool with the classified weapon, sensor, and emitter/jammer routines provided by XCITE. Selected entities may then be published to the network with DIS packets being generated by both applications that split their responsibility for modeling the players which, effectively, will be constructive entities behaving with some characteristics of virtual cockpits. Continued R&D in this area would leave the complex, classified data and routines processing within XCITE while the flight parameters and characteristics would be developed and enhanced within the XPlane program. Additionally, users would get the benefit of realistic control of flight with a joystick instead of having to use a mouse and keyboard, and will have a 3D view not currently available in the Threat IOS application. The outcome of this proposed effort would mean XCITE will publish the necessary information, which the XPlane graphics routines use to simulate cockpit display screens and the head up display (HUD). Therefore, entity modeling and control, as well as scenario visualization will be distributed among tools that may be better suited for the tasks.

2.3.2.12 Identification Friend or Foe

WRSTP engineers enhanced AFRL's XCITE to model IFF mode 4 rollover and also modified the Threat IOS application to present current IFF status for a given player entity in ways that are better for the users.

2.3.2.13 Scripted Tactics and Behavior

The WRSTP team explored usability of GUIs for building and running training scenarios, which have constructive entity tactics and behavior executed under control of a script.

The primary goal of this research was to develop a more efficient way to build scripts. Previously, the government's XCITE application provided the user only one way to build an entity script. An Access database accepted user inputs and stored the script information in a scenario initialization data file. The data was read into the application's memory space when the user selected a predefined scenario. We defined entity characteristics and initial position, along with script parameters, before the training event began and they could not be changed while the loaded scenario was still executing.

End-users in the operational training community, as well as research scientists and the primary investigators for this task, found the existing scripting tools and techniques to have little value. This was true because the capabilities of this application to run scripts, and the existence of a user front-end on the database tool, was not adequate because they required experienced, highly trained individuals with computer science, physics, and engineering backgrounds to perform a very complex and tedious task which most people would not or simply could not do themselves.

A secondary objective was to reduce or eliminate the need to enter and store duplicate script parameters for pairs or groups of constructive entities assigned to follow the exact same script. Users desire the ability to have a vast library of predefined, customized scripts, which they may select at any time and assign an entity or a group to follow or execute. Additionally, users want to provide extra parameters unique to any given combination of an entity and a script. For instance, a script containing an instruction to attack a target need not define exactly which target until an asset entity is assigned to execute the script. At the script assignment stage, end-users want to be able to define target type, position, and type of ordnance to deliver. For this example, one single script can be used for four airborne assets. Each may have its own unique target and/or ordnance selection, but all other script parameters may be considered common.

Another important part of this research was to develop a way for XCITE users to visualize scripts while player entities are executing them. Looking at an IOS terminal, the instructors and scenario providers want to see where an entity is within its assigned script. They want to quickly view which instructions have completed, which one is currently being executed, and what is to come and under what conditions those will occur. Users need to be able to anticipate what will soon transpire or occur in a scripted training event, and they want to be able to do this without having to memorize the whole event beforehand.

Finally, it is necessary for one to be able to build, adjust, or otherwise edit a script at any time during a simulation event or scenario that is running. Likewise, anyone should be able to reassign an XCITE player entity to cease execution of a script and then follow a different script or, as in the example above, change ordnance type in a script that has an instruction to attack. Users want to have an assigned entity be able to leave a script, perform some other user-defined task or operation, and then easily return to the previously assigned script at the point where it left off or enter back in at a different instruction in the script.

The WRSTP team made enhancements to the Threat IOS to improve the building, editing, and assigning of XCITE scripts. We created new dialogs, menus, and mouse actions to support this effort. We developed new XCITE script symbology and it mirrors much of what Massachusetts Institute of Technology (MIT) created for the educational computer program named Scratch. We built upon existing DIS network interfaces between Threat IOS and XCITE to exchange script editing messages and status information. These network interfaces do need more work to iron out minor software bugs as well as complex issues with the design. We modified the scenario-spawning algorithm in the XCITE application to use a common script library and entity-specific script parameters. The engineering team recommends continued research and development of the necessary software enhancements to improve usability of XCITE entity scripts.

2.3.2.14 Wheel Tactic

Using input provided by JTAC SMEs, the WRSTP team resumed developing the Wheel tactic that was first introduced in the AFRL's XCITE software source code in 2005 but not made ready for use. We designed, coded, and integrated all new GUIs to allow scenario providers to command a group of constructive entities to fly the wheel tactic. Further research is needed to iron out software design issues in XCITE so that the aircraft can drop its ordnance load and return to the wheel pattern, as expected.

2.3.2.15 Lifeform Interactions

The WRSTP team developed within the XCITE database a new weapon modeled on an M-16 rifle. They also modified the database to attach the M-16 weapon to a soldier lifeform entity. Now, instructors operating a simulated mission may create and control multiple XCITE soldier entities. We modified the application's tactics algorithms to provide the operator the means to manually command soldiers to attack, shoot, damage, and kill other opposing lifeform entities. We enhanced the targeted soldiers' tactics to react to the detonations or bullet impact points when land-based platforms or other lifeforms attack soldiers on the ground. WRSTP engineers developed the lifeform tactics to cause the soldiers to move away from the fire and then react by returning fire.

WRSTP engineers also modified the XCITE application to accept instructor commands to cause lifeforms to board a given vehicle or disembark the vehicle. Once onboard, the vehicle entity can be commanded by the instructor to move under control to another location while the lifeforms remain onboard for the duration of the trip. WRSTP engineers developed the application so that entities can be boarded one at a time (as many as four per vehicle). When they disembark, all lifeforms react at once when the instructor gives the command to get out of the vehicle.

2.3.2.16 Patrol Tactic

This tasking included work performed by the WRSTP team to develop the XCITE tool to simulate a new patrol tactic for ground-based lifeforms and vehicles. The scenario provider uses Threat IOS to specify the speed and direction of the patrol, the location and the assets, as well as the number of laps through the assigned maneuver area before the entities continue with the next user-defined action.

2.3.2.17 Rules of Engagement

WRSTP engineers considered options to enhance the XCITE tool to improve user-defined player entity rules of engagement. However, the work did not culminate in a change to the software baseline. This work should be continued because the user community, in recent meetings, did offer information that illustrated the value of this needed feature. A –permission to engage”

option should be given to player entities created by or controlled internal to XCITE. Command and control rule sets should be easy to setup and modify; this additional work should be accomplished as time and funds allow the team to continue their effort.

2.3.2.18 Route Maneuver Enhancements

Responding to feedback provided by end-users, the WRSTP team collaborated to develop the tool's ability to fly or otherwise move constructive entities along a predefined route. We modified the XCITE program to accept user inputs and apply them to the route maneuver so that single entities or groups of players would perform a variety of actions. The legacy software routines still offer the ability to begin a route at a selected waypoint and go along the remainder of the waypoints until arriving at the end of the route. When an entity arrives at the last route waypoint, new capabilities allow the user to choose to command the assigned entity to either automatically loop back around to the beginning waypoint and repeat the maneuver or to turn around 180 degrees and return on the path in the reverse direction. Users may now command an XCITE entity to repeat these actions a certain number of times before performing any subsequent tactics or maneuvers. For land vehicles driving a route, or even for lifeforms walking along a predefined path, the scenario provider may also choose to have the assigned player entity slow down and stop briefly at each waypoint.

2.3.2.19 Datalink Setup and Control

Further research and development is needed to improve the way scenario providers in a DMO environment will setup, control, and use simulated radio datalinks. Existing user interfaces, while useful for integration checkout and test, should be made easier to operate when using XCITE during training exercises. Instructors and operators want to see and feel datalink displays, which are similar to panels and screens used in the aircraft and by ground personnel. They are already familiar with working systems like those they use in the field, and they often expect the training environment will employ similar tools and interfaces. AFRL's government-owned software applications should also be modified so that repetitive and tedious actions may be minimized where possible when using XCITE to train datalinks.

Further development is recommended to give XCITE datalink software routines the ability to automatically generate surveillance track numbers. Additionally, effort should be applied to make it easier for scenario providers to search for track numbers in a DMO training event and visualize the datalink picture.

2.3.2.20 Chaff Timeout

The WRSTP team modified the software source code in XCITE to cause chaff entities to be removed from the simulated scenario following a period of time. Previously, the entities remained for an unnecessarily longer period, which tied up the computer's memory space and made it unavailable for use with other, more current entities.

2.3.2.21 Optical Sensors

Simulated human vision and the ability of XCITE lifeform entities to detect and track moving or stationary objects is research and development work that should continue. The WRSTP team has observed an inadequate manner or ability in which XCITE performs the functions of optical sensor target acquisition and tracking, and explored possible solutions. However, insufficient time was available to complete this study under TO 0037 or to propose a working solution.

2.3.2.22 DIS Output Buffer Size

XCITE has an output buffer that can hold 300 DIS packets. If a query request comes in for a list of all player models, then XCITE will push its response into that buffer and this takes up more than a third of the available space. While the XCITE NIU is pushing out the packets, the application may receive another query request. Its response will be added to the queue, whether it is one packet of tactical area coordinates, 125 packets of additional player model information such as jammer capabilities or passive detection parameters, or a packet containing a response to a request for only 64 bits of information for a single player entity.

If requests come in faster than XCITE can respond then the console will print messages indicating an overflow error condition and the requesting application will not get the expected response. The WRSTP team explored this and observed the Threat IOS display, dialogs, and menus were getting stale because XCITE was busy or overloaded with requests for information. They developed a modification to address this by throttling the queries that Threat IOS sends to XCITE. It waits to receive all packets for each request before sending the next request to XCITE. Potentially, any other application, which communicates with XCITE, may still experience problems unless it does something to slow the flow. The modification puts almost all requests for information into a queue. This queue would be controlled inside the Threat IOS to limit the possibility of XCITE's output buffer filling up.

2.3.2.23 Coordinate System Selection and Resolution

Scenario providers in the operational training community who use the government-owned XCITE program were critical of the fact that the manual task of creating a constructive entity offered too few options for defining the player's initial position. There existed a few different means of choosing or entering a location developed previously under other task orders. The Mesa Research Site further developed a customizable user interface for selecting the coordinate system used by the Threat IOS application. The new options include universal transverse mercator (UTM) and military grid reference system (MGRS), in addition to the legacy Lat/Long format. Also, the operator may customize the Lat/Long entry to be provided in either DD:MM:SS or DD:MM.MMMM, and may further choose the resolution of the decimal minutes entry to be any number of decimal points from one to six. R&D work that began but did not complete before the closure of this task included modifications to another Threat IOS dialog that accepted user inputs for target position when setting up for commanding fire missions. End-users want to be able to enter target coordinates relative to the position of friendly ground forces, in addition to the currently available option of simply entering latitude and longitude. We recommend developing, testing, and fielding and applying the new format and resolution options described above to other existing Threat IOS user dialogs that accept coordinate inputs. Additionally, adjustments should be made to the application software so that the cursor can be moved automatically from one dialog entry field to the next when the user presses the tab key while entering coordinates and other parameters.

We recommend enhancing AFRL's XCITE and Threat IOS computer program software to support Global Area Reference System (GARS). GARS is used to rapidly and clearly define geographical locations for battle-space coordination, deconfliction, and synchronization as well as for large-area search-and-rescue efforts. Unlike the geographical grid systems used for the different operational areas, GARS is global in scope, providing a common language between the services/combatant commands and simplifying communications. GARS provides a common language to describe 30 x 30, 15 x 15, and 5 x 5 minute areas unless the combatant commander

determines that the use of another area reference system is mission critical. It provides the two-dimensional (2D) construction from which control and coordination measures can be constructed. It is not used to describe exact geographic locations or to express precise positions for guided weapon employment, or to describe areas smaller than 5 minutes by 5 minutes.

2.3.2.24 Weapon Load Outs

CGF applications including XCITE and Threat IOS should undergo further development to give end users a simple, intuitive way to adjust the weapon load out of an entity that has already been created in the DMO environment. Alternatively, one in which the user wants to create but with a different weapons load than the default settings that are stored somewhere in a database.

2.3.2.25 Inflight Weapon Status

WRSTP engineers explored what would be necessary to enhance the Threat IOS application to present to operators detailed up-to-date status of inflight weapons that are created by a virtual cockpit operation in a DMO event. Recommended work includes enhancements to the network interfaces of cockpit devices in order to publish special purpose DIS data PDUs. The information contained in each packet would then have to be parsed by the Threat IOS and be stored in local memory. The graphical presentation on the Threat IOS should be enhanced to allow the user to browse, choose, and review weapon modes, electronic warfare emissions, jamming effectiveness, and energy.

2.3.2.26 Cognitive Study of the XCITE GUI

The WRSTP team enhanced the XCITE GUI to reduce button selections used to turn on and off various symbols, icons, and readouts shown on the Threat IOS display. The buttons had been arrayed in a static layout that gave users no option to rearrange their appearance. This resulted in an inordinate amount of time required to locate any given button. The modification we introduced makes buttons user-customizable to a large degree. Future growth of DMO training devices similar to and including the Threat IOS application should be designed or redesigned, where practical, to give end-users more control over the appearance of their user interfaces and controls. This will further reduce tedium and operator workload.

2.3.2.27 Symbology

The WRSTP team observed that end-users and research scientists want unique symbols displayed on a CGF IOS for representing simulated entities, which may be relatively similar in many regards except for instance, country of manufacture or antenna height. Our engineers modified Threat IOS to give users a way that they can individually define the symbol and associated descriptive text for all known (and unknown) types of sensors and emitters defined in Simulated Interoperability Standards Organization and Combat Air Force (CAF) DMO standards. If users want more ability to define appearance color or font type and size then work should continue to enhance Threat IOS symbology software and data tables.

2.3.2.28 User Preferences

Multiple users assigned to use the same GUI to conduct DMO training events that occur at different times and across several work shifts and workdays are users that are seeking a solution to an ongoing problem with setting personal preferences. The WRSTP team observed that research scientists and end-users wanted to set their own user preferences with the XCITE CGF and Threat IOS GUI. Additionally, they did not want to be forced to use other user's preferences or have to restore settings when they were finished with their work shift. A low-risk, low-cost

solution to this problem is very possible but it has not been implemented due to other higher priority taskings.

2.3.2.29 Areas and Boundaries

WRSTP engineers enhanced the XCITE CGF to make use of user-defined areas and boundaries in the employment of player tactics and maneuvers. Unfinished work includes additional changes to easily create and edit the associated data and to view them on the Threat IOS display.

2.3.2.30 Joint Precision Airdrop System (JPADS)

Four members of the C-17 training community met with AFRL government personnel and four WRSTP XCITE development team members. Visiting AFRL was John W. Hagin, USAF AFMC HQ AFMC/A4VQ, Rob Gomez, C-17 Program Manager, Maj Paul Adams, and TSgt Joshua Hoekstra. The topic of the meeting was training requirements involving weather measurements transmitted by the radiosondes the C-17 loadmaster drops prior to when the aircrew lands or prior to dropping cargo palettes. We also discussed simulating the guidance mechanism mounted atop the cargo palette. The visitors described preflight tasks and sortie operations, which they need to provide training. The C-17 community explored use of AFRL's XCITE application to provide the input to their laptop computer on an Ethernet port. The visitors stated that there is no cost effective simulation that can train for these tasks. Training currently occurs during sorties at Ft Sill and does not provide complete training of all tasks.

2.3.2.31 Entity Pairing Status

End-users and research scientists require status and feedback about the interactions between pairs of entities engaged with one another in a DMO training event. Using XCITE CGFs, they observed sensor mode changes but could not easily or accurately ascertain the reason or cause for the mode change. Likewise, weapon engagements did not previously occur with the requisite status information displayed on a screen for users to determine why a weapon did not fire or why a different weapon fired than expected. In the XCITE design, these conditions are known by the algorithms that process sensors and weapons. Previously, the information was not published or displayed. The WRSTP team enhanced the XCITE NIU and Threat IOS to display more information to help the user understand and know what is happening in the decision logic within XCITE while a scenario is playing out. Users should be solicited about the type of information that they want to see displayed during training events.

2.3.2.32 Classification Level

The WRSTP engineers enhanced XCITE to add a security measure that checks the classification levels of scenario and model data files to make sure they match the user's intent when preparing to begin a training mission. Previously, it was possible to mistakenly initialize a classified mission even if the application was in an unclassified mode of operation.

2.3.2.33 Database Schema and Forms

Previously, AFRL's XCITE Access database was a binary object. Changes customarily made by any engineer to the XCITE Access database were not directly visible to other developers. There had been no easy means to visualize independent changes of individual modules. WRSTP engineers created a new Access database module that extracts all data objects into text files that are human readable and that can be imported back into the database. This facilitates configuration management (CM) by allowing the CM system to track schema, form, report, and even data changes at a text level rather than tracking alterations to a binary object.

2.3.2.34 *XCITE Training Classes*

Over the course of the task order, the WRSTP team has had several opportunities to train visitors how to use and collaboratively develop the XCITE application. Trainees benefited from learning first-hand from experienced research and development engineers how to effectively apply the capabilities of the tool, contribute information to the database, and enhance the computer algorithms. In addition to the documentation and training videos prepared, the user community and co-developers gained insight into the inner workings of XCITE and gained knowledge of how to further develop the software suite for their unique needs and requirements.

2.3.2.35 *Electronic Warfare/Electronic Attack Debrief Capability*

The WRSTP team built a questionnaire in Excel that received the research psychologist's approval. The psychologists were impressed the knowledge of research techniques and concerns, and made only minor changes—mostly in the demographics area. The team decided to use Access vs. Excel, as Access is a more powerful program in this application. AFRL government personnel received the approval of the Institutional Research Board (IRB) to use the questionnaire. The questionnaire was never administered because of the lack of test subjects due to the schoolhouse closing down.

2.4 Audio Integration/Demonstrations

The application *listen* renders audio for entities as well as detonation and fire events in three spatial dimensions relative to a listener. The listen software was government furnished, provided by 711 HPW/RHCB. The WRSTP team demonstrated the feasibility of integrating *listen* spatial audio into the Joint Terminal Attack Controller (JTAC) Training and Rehearsal System (TRS), which includes a 3D environmental sound capability to increase immersion in the simulated battlefield.

2.4.1 Methods, Assumptions, and Procedures

Examination of *listen* source code revealed that it could not be used as-is. While it provided the functionality desired by the team, it relied heavily on the VR-Link networking toolkit libraries developed by MäK Technologies. Use of these libraries would have required the purchase of licenses from MäK. The cost – exceeding $10,000 for a one-time purchase – rendered this option impractical.

Listen is an application that mainly processes entity state updates and fire/detonation events, and sends the AudioServer the necessary data regarding the location of each potential sound source relative to the listener. We decided to start from an unclassified version of the host used by the Radio Frequency Threat Environment (RFTE). This host (hereinafter referred to as the Spatial Audio Host), was originally designed as a passive application that listened to distributed interactive simulation network (DISNET) and processed entity states and other distributed interactive simulation (DIS) events including fire and detonation events.

The approach decided upon was to remove the functionality related to text-to-speech (which JTAC does not use), and add the necessary AudioServer/slab3d calls to the application, using *listen* as a guide for updating entity states and handling fire/detonation events vis-à-vis the AudioServer library calls. Additionally, since a different head tracker was used on site than at Wright-Patterson Air Force Base, code would be added to read the tracker data broadcast by the

JTAC observer's compass to provide the necessary listener orientation information to the AudioServer; trackDAPI would not be used.

2.4.2 Results and Discussion

The WRSTP team integrated and demonstrated existing 711 HPW/RHC-provided audio tools into AFRL/RHA simulation systems, specifically the JTAC-TRS. We provided technical information that supported a common architecture definition and system and software development, with consideration of DIS/high level architecture (HLA) protocols, of a single set of improved spatial (3D) audio tools that can be used to maintain multiple types of voice communication on a network (voice, chat, speech-to-text, text-to-speech, speaker location, etc.).

2.5 Ultra-High Resolution Deployable Projector Components for Simulation

Initially this effort focused on developing and testing optical components for micro-electro-mechanical based laser projectors for immersive environments. The focus shifted to investigating and developing specifications and standards for the acquisition of visual systems for simulation (Immersive Display Evaluation and Assessment Study [IDEAS]).

2.5.1 Methods, Assumptions, and Procedures

Work began by collaborating with Alces Technology to integrate display technology components into existing government furnished projectors at the Mesa Research Site. Based on this integration, the plan was to define image generation requirements, purchase and/or develop required hardware and software, and interface the projectors to their respective image generation systems. Upon completion of the system integration, human perceptual and engineering tests to characterize the functional performance of the display systems were to be conducted.

In late 2009, AFRL and Aeronautical Systems Center (ASC) proposed and initiated Phase I of IDEAS, which launched in the summer of 2010. The following are some of the long-term goals of this program:

- Develop display system performance requirements for Air Force programs that are defensible based on training task performance.
- Define metrics and methods of measuring display systems to assess conformance with the requirements.
- Define the requirements for a decision support system (DSS) that would provide stakeholders ready access to the requirements, metrics, and measurement procedures.
- Demonstrate the utility of the approach so that long term funding might be secured to sustain the extension and maintenance of the requirements and DSS.
- Monitor and facilitate the development of the DSS by a third party and feed the developer content to extend the system.

For the first phase of the IDEAS program, the scope was limited to fast jet training of daylight operations with an emphasis on the F-16 Mission Training Center (MTC). Discussions with fast jet subject matter experts (SMEs) resulted in selecting the aircraft visual identification task for the first modeling effort. Discussions with key Air Force acquisition professionals produced a list of display design parameters that were in need of development or rework. High on the list of priorities was the need for a requirement and metric that regulated the motion induced blurring.

The team focused its efforts on the effects of five variables expected to be the primary determinants of task performance with moving images on high-resolution display systems. These five variables included: angular velocity of the image, pixel hold time, pixel pitch, display luminance, and display contrast.

During the fall of 2010, a model of the effects of these and related variables on aircraft identification range was prepared and initially tested using the data from the few evaluations found in the literature. The paper presented at the 2011 IMAGE Conference (Lloyd, Williams, and Pierce, 2011) describes the model and initial validation.

Over the next few months, the team composed and conducted two laboratory evaluations to collect a much larger set of data to validate and tune the model. Across these two evaluations, we measured aircraft identification range as a function of 420 combinations of the settings of five design variables: pixel hold time, angular velocity, pixel pitch, display system luminance, and display system contrast.

2.5.2 Results and Discussion

The collaboration with Alces Technology Inc, to develop and test optical components for micro-electro-mechanical based laser projectors was suspended by mutual agreement between Alces and the Government. This collaborative work initially consisted of upgrading AFRL's Evans and Sutherland Laser Projector (ESLP) with new optical and Micro-Electrical-Mechanical Systems (MEMS) components developed by Alces. As technology development continued, it became apparent that these new components were incompatible with the ESLP. This led to the suspension of any direct collaboration between Alces and L-3. The government redirected the L-3 to focus on developing the human perceptual and engineering tests used to characterize the functional performance of displays, such that these tests will be fully developed to employ on next generation display systems, including the display technologies being developed by Alces Technology. This development of functional performance metrics is the IDEAS research effort. The WRSTP team researched and developed methods for evaluating the fidelity of immersive environment display systems.

The IDEAS program was initiated in the summer of 2010. The long-term goal of this program is to produce a DSS that will (1) enable Air Force acquisition professionals to rapidly generate defensible display system requirements given a set of training task requirements, (2) enable suppliers to develop new visual systems and prepare proposals, and (3) aid certifiers to measure performance. Some overarching goals for the DSS include the following:

- Usable by persons who understand the training need but are not experts in current display technology
- Produces defensible requirements based on task performance data and previously validated models
- Identifies the data and models that underlie each recommendation
- Allows high level design trades to be made during the requirements generation process
- Produces the specific text and levels for selected display system requirements
- Provides the approved measurement procedure for each requirement
- Employs an architecture that allows updating the data and models as technologies evolve

Development and validation of the first model/data to be incorporated into the DSS began in the fall of 2010. This work is summarized in technical reports and two papers presented at IMAGE

2011. The papers and presentations describe the general capabilities of the DSS and provide concrete examples of the following:

- Generation of selected display requirements from the F-16 MTC training task list
- Use of the DSS to make source selection decisions
- Generation of measurement procedures
- Use of the DSS by a supplier for product development planning

Two evaluations, conducted at the Mesa Research Site using F-16 subject matter experts as participants, were used to test, validate, and tune the model.

3.0 CONCLUSIONS

This final report summarizes work completed in support of Task Order 0037, Entity Modeling and Immersive Decision Environments research and development. More in-depth documentation is available by reviewing the technical reports and presentation materials cited in the Annotated Bibliography.

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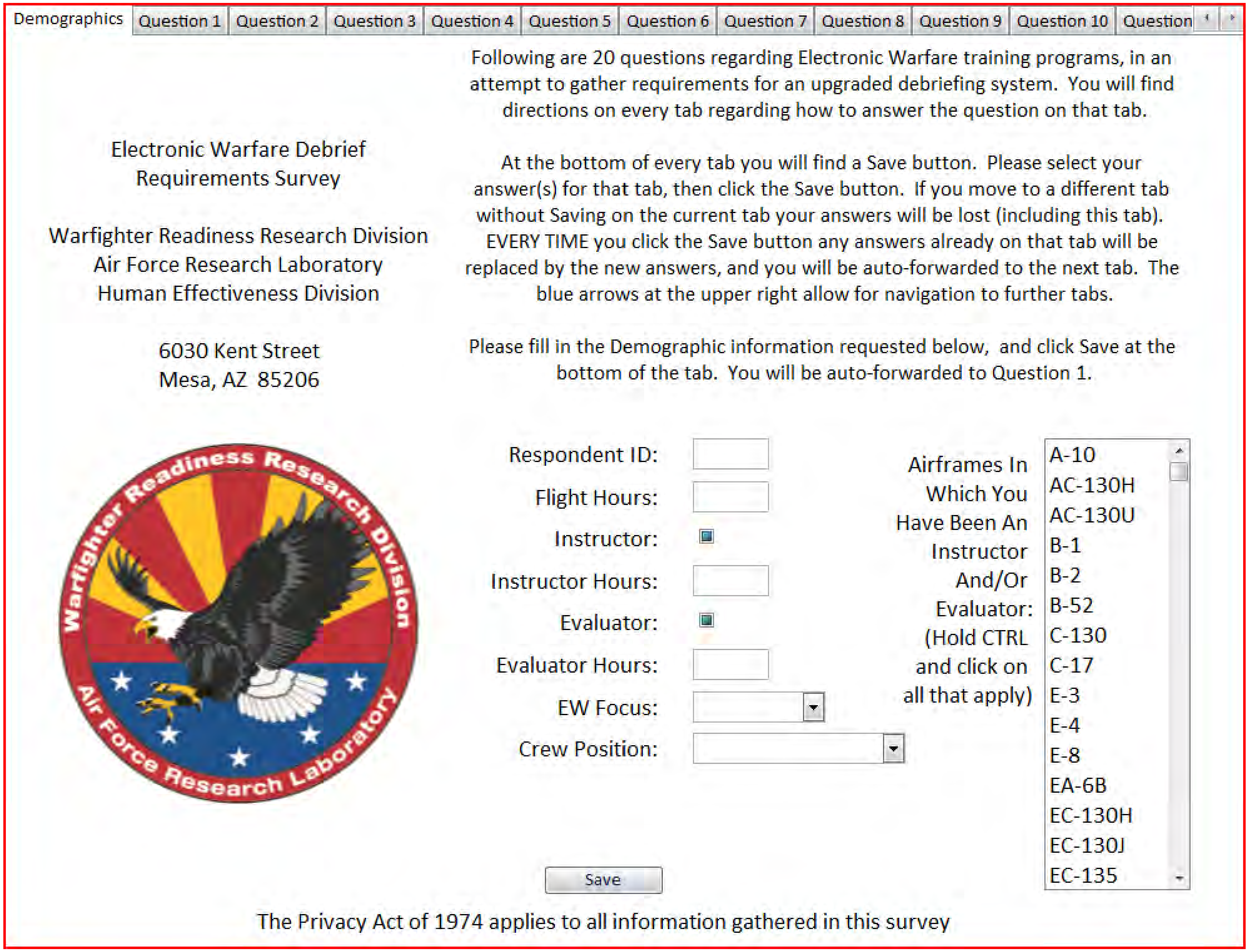
APPENDIX – ELECTRONIC WARFARE REQUIREMENTS SURVEY QUESTIONNAIRE



Demographics | Question 1 | Question 2 | Question 3 | Question 4 | Question 5 | Question 6 | Question 7 | Question 8 | Question 9 | Question 10 | Question

Electronic Warfare Debrief
Requirements Survey

Warfighter Readiness Research Division
Air Force Research Laboratory
Human Effectiveness Division

6030 Kent Street
Mesa, AZ 85206

Following are 20 questions regarding Electronic Warfare training programs, in an attempt to gather requirements for an upgraded debriefing system. You will find directions on every tab regarding how to answer the question on that tab.

At the bottom of every tab you will find a Save button. Please select your answer(s) for that tab, then click the Save button. If you move to a different tab without Saving on the current tab your answers will be lost (including this tab). EVERY TIME you click the Save button any answers already on that tab will be replaced by the new answers, and you will be auto-forwarded to the next tab. The blue arrows at the upper right allow for navigation to further tabs.

Please fill in the Demographic information requested below, and click Save at the bottom of the tab. You will be auto-forwarded to Question 1.

Respondent ID:
Flight Hours:
Instructor:
Instructor Hours:
Evaluator:
Evaluator Hours:
EW Focus:
Crew Position:

Airframes In Which You Have Been An Instructor And/Or Evaluator: (Hold CTRL and click on all that apply)

A-10
AC-130H
AC-130U
B-1
B-2
B-52
C-130
C-17
E-3
E-4
E-8
EA-6B
EC-130H
EC-130J
EC-135

Save

The Privacy Act of 1974 applies to all information gathered in this survey

Figure A.1. Demographics

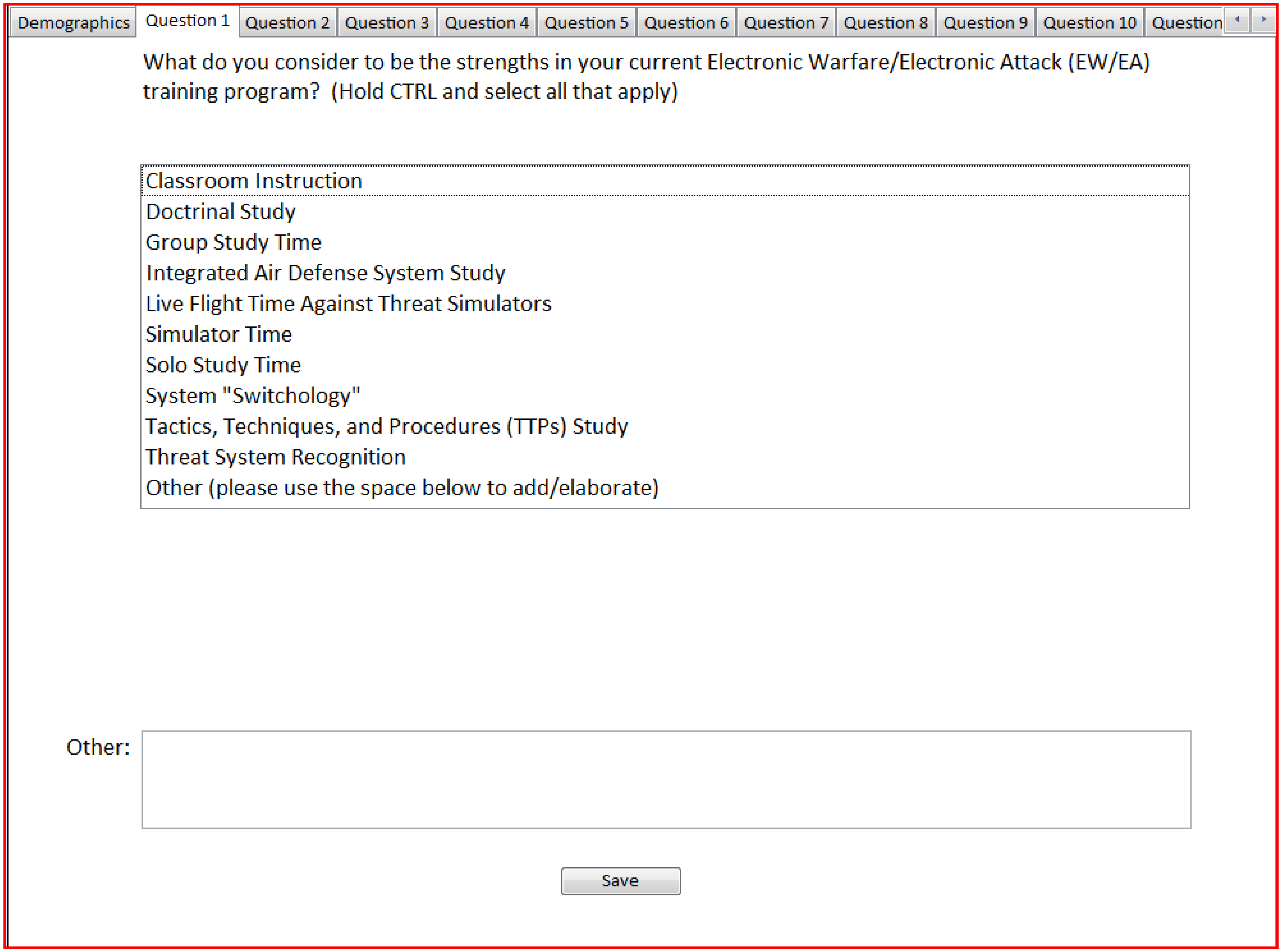
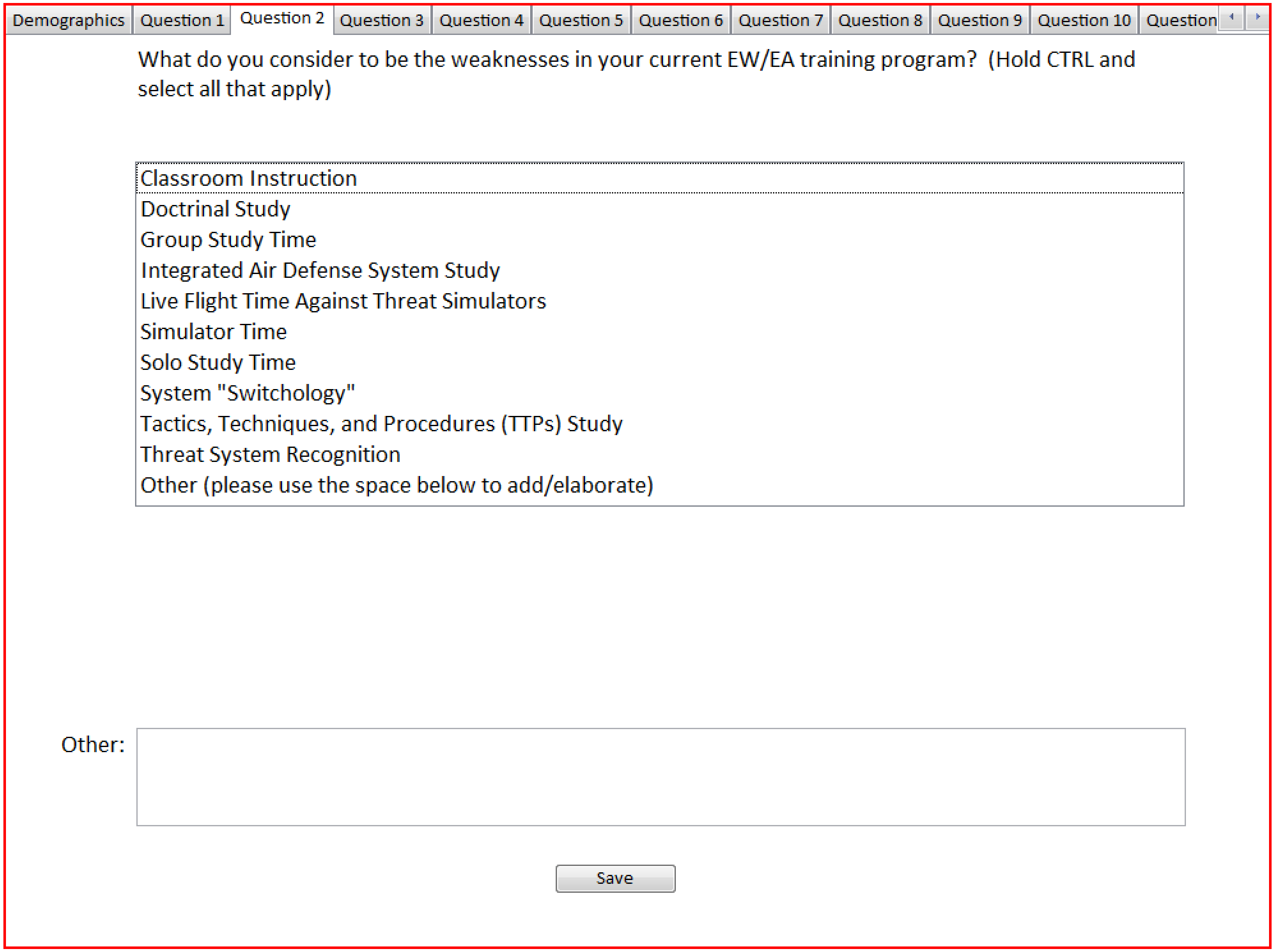


Figure A.2. Question 1



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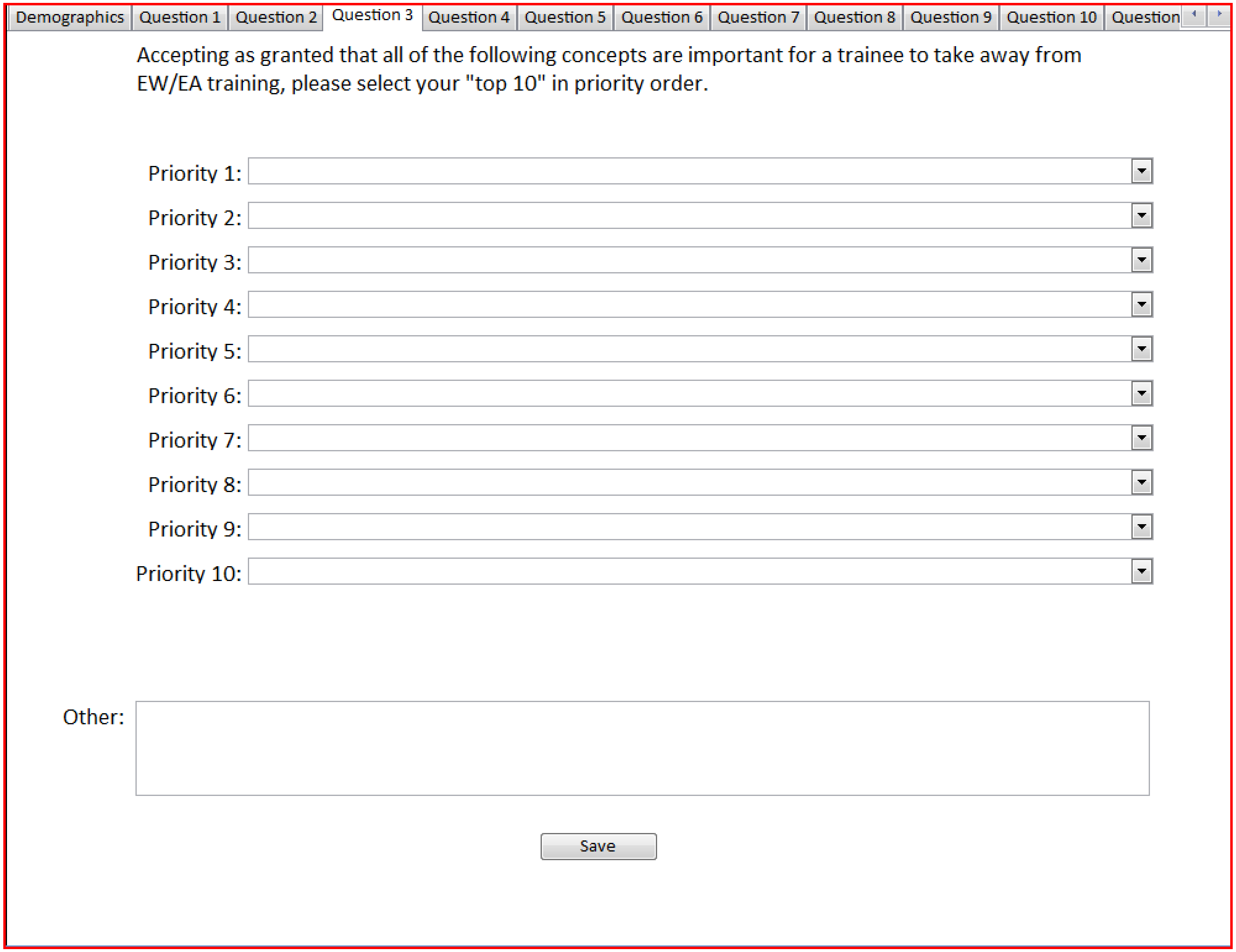


Figure A.4. Question 3

Figure A.5. Question 4

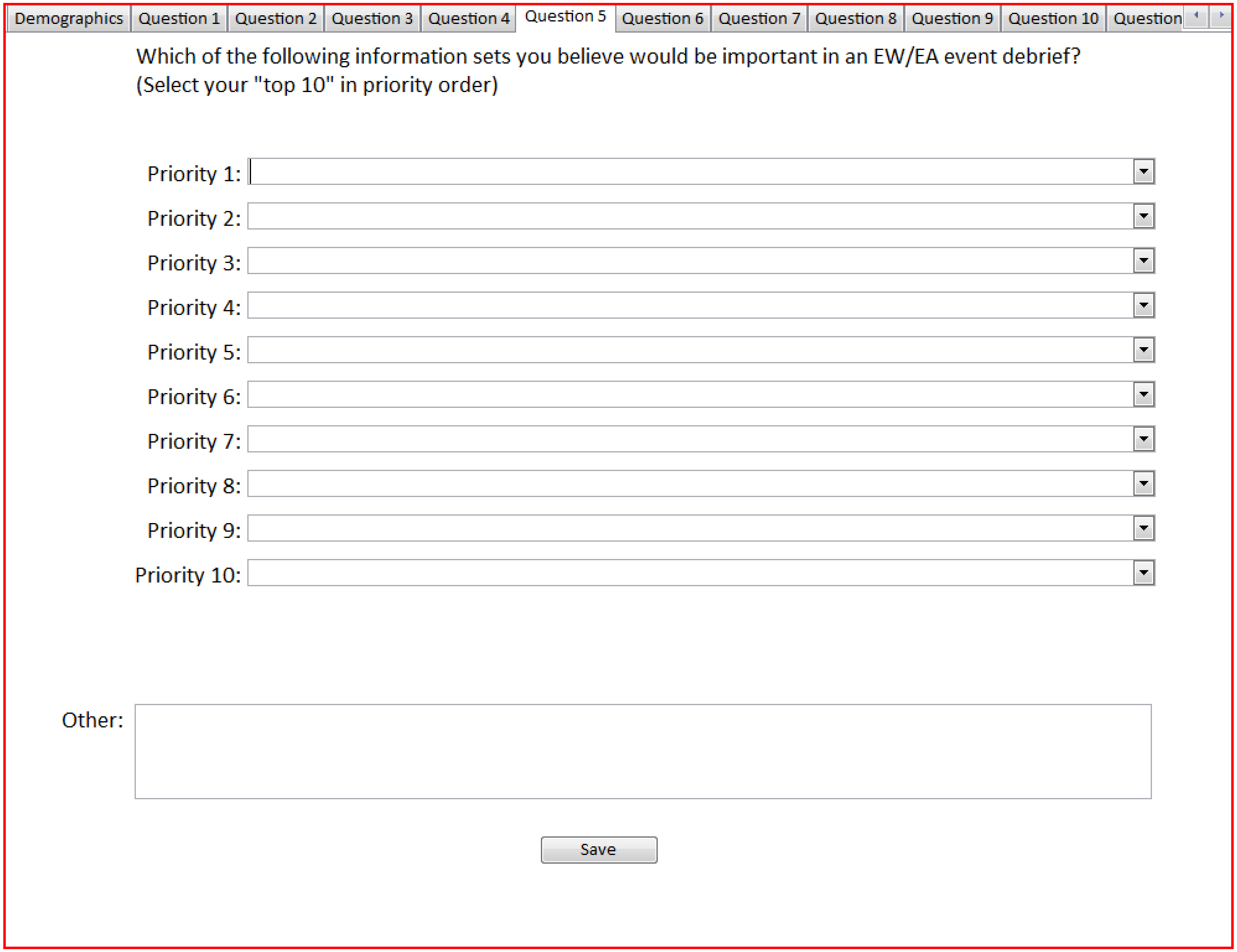


Figure A.6. Question 5

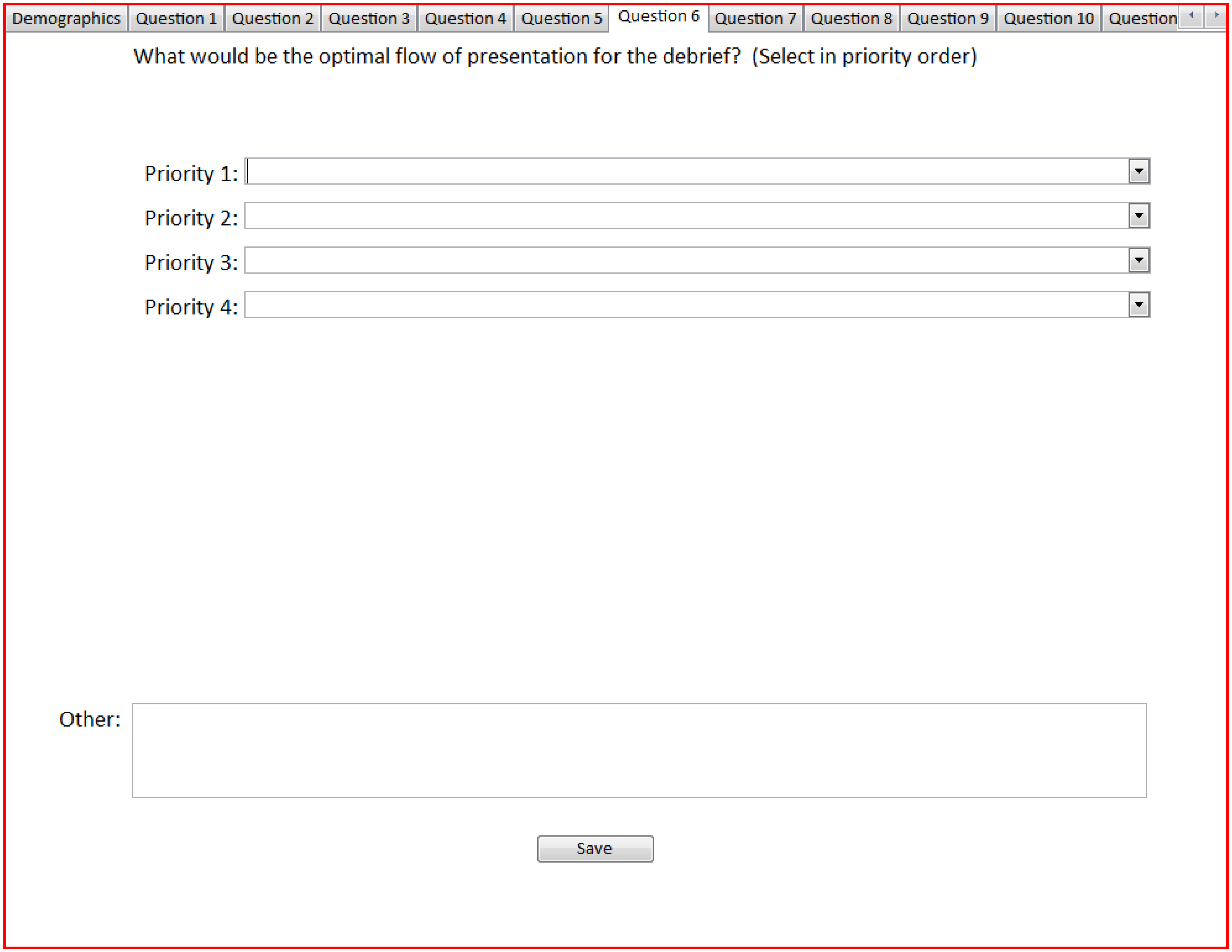
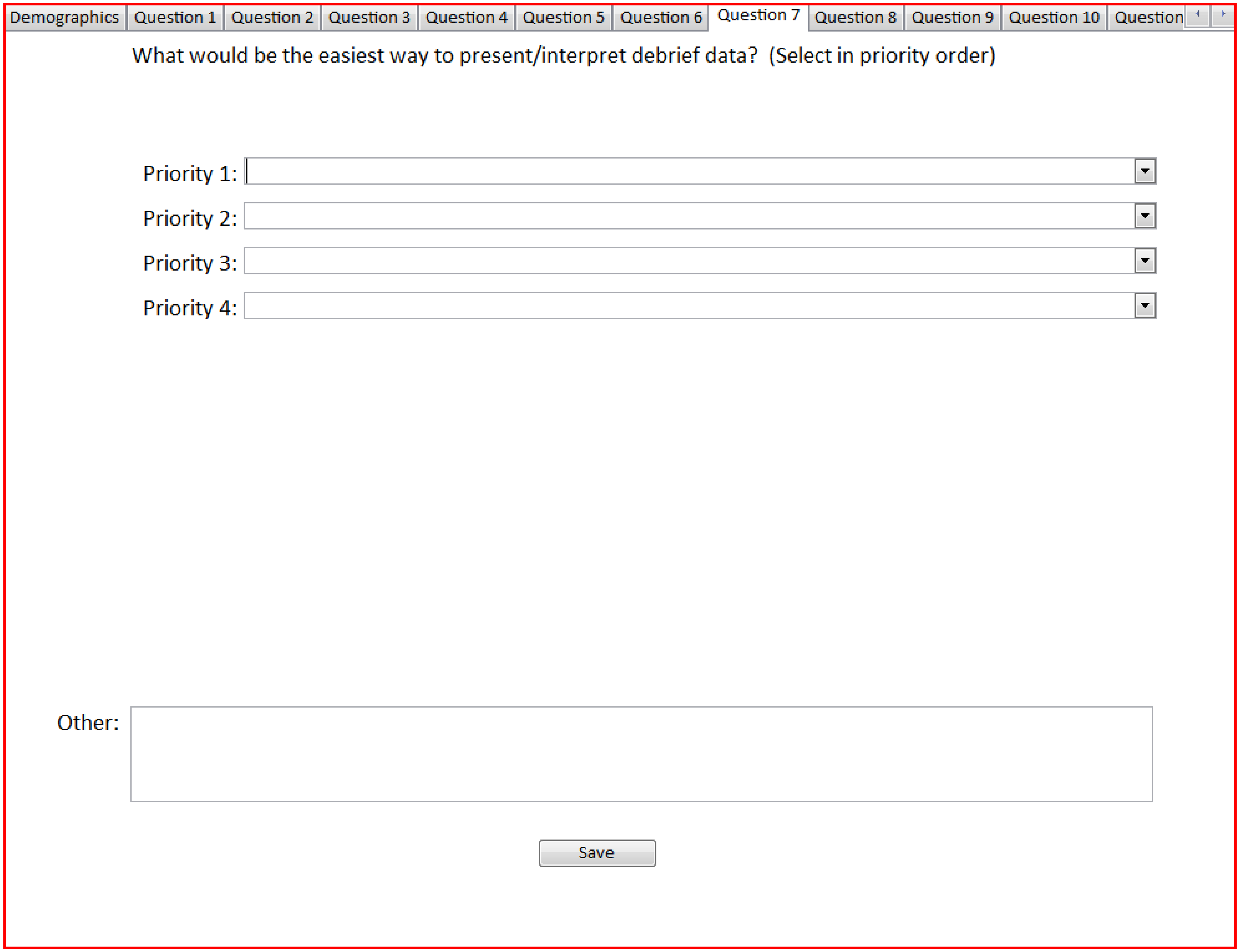


Figure A.7. Question 6



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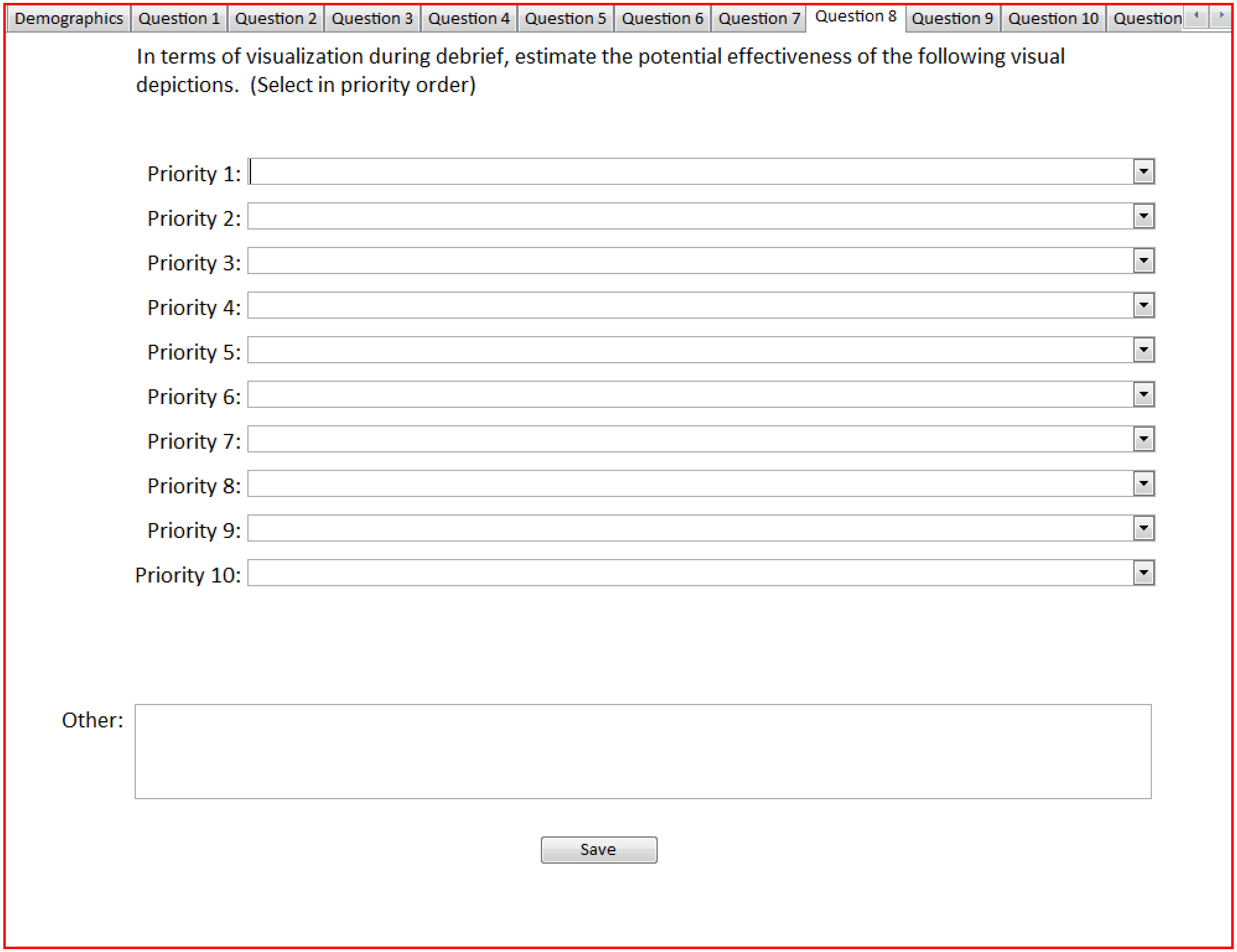


Figure A.9. Question 8

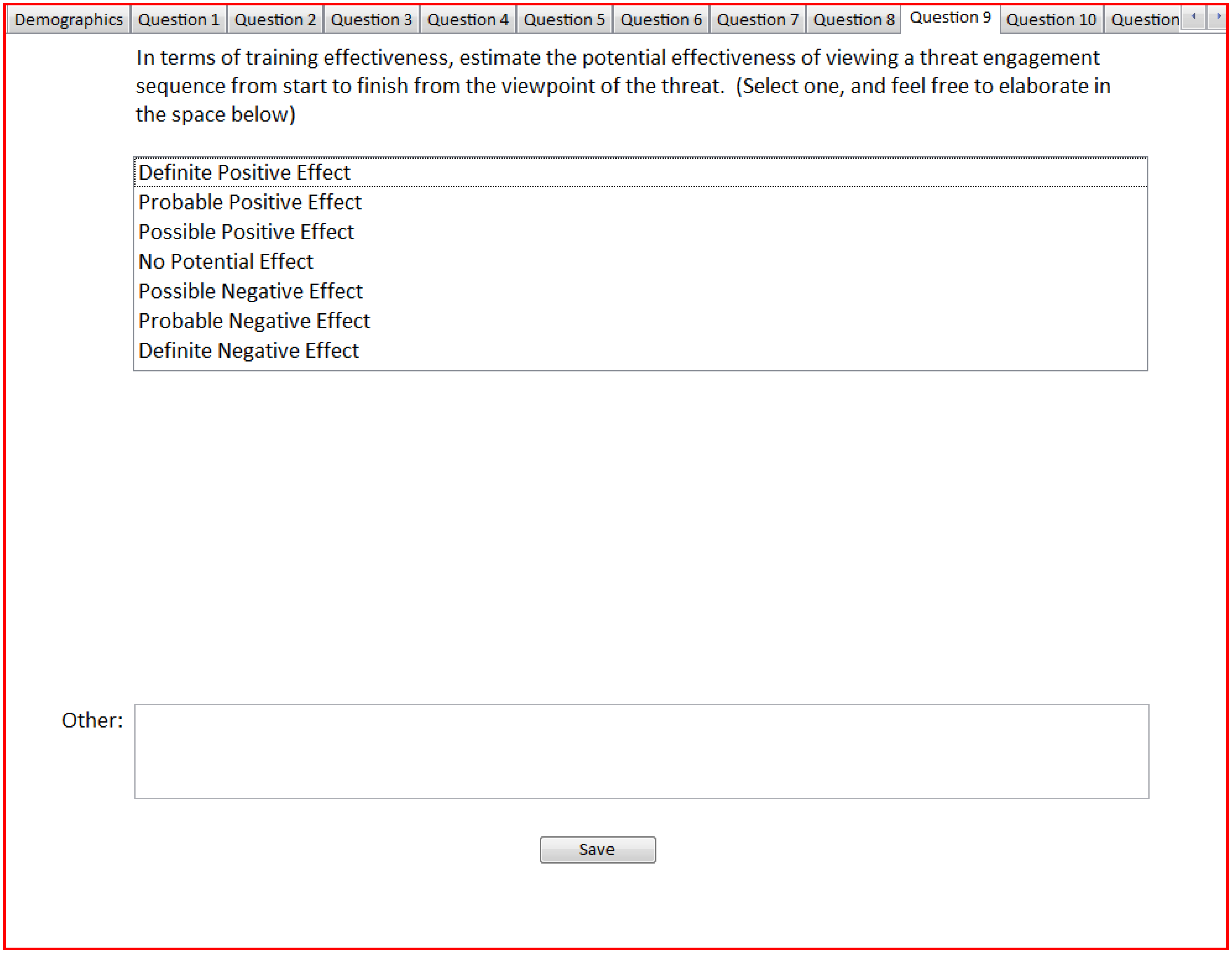
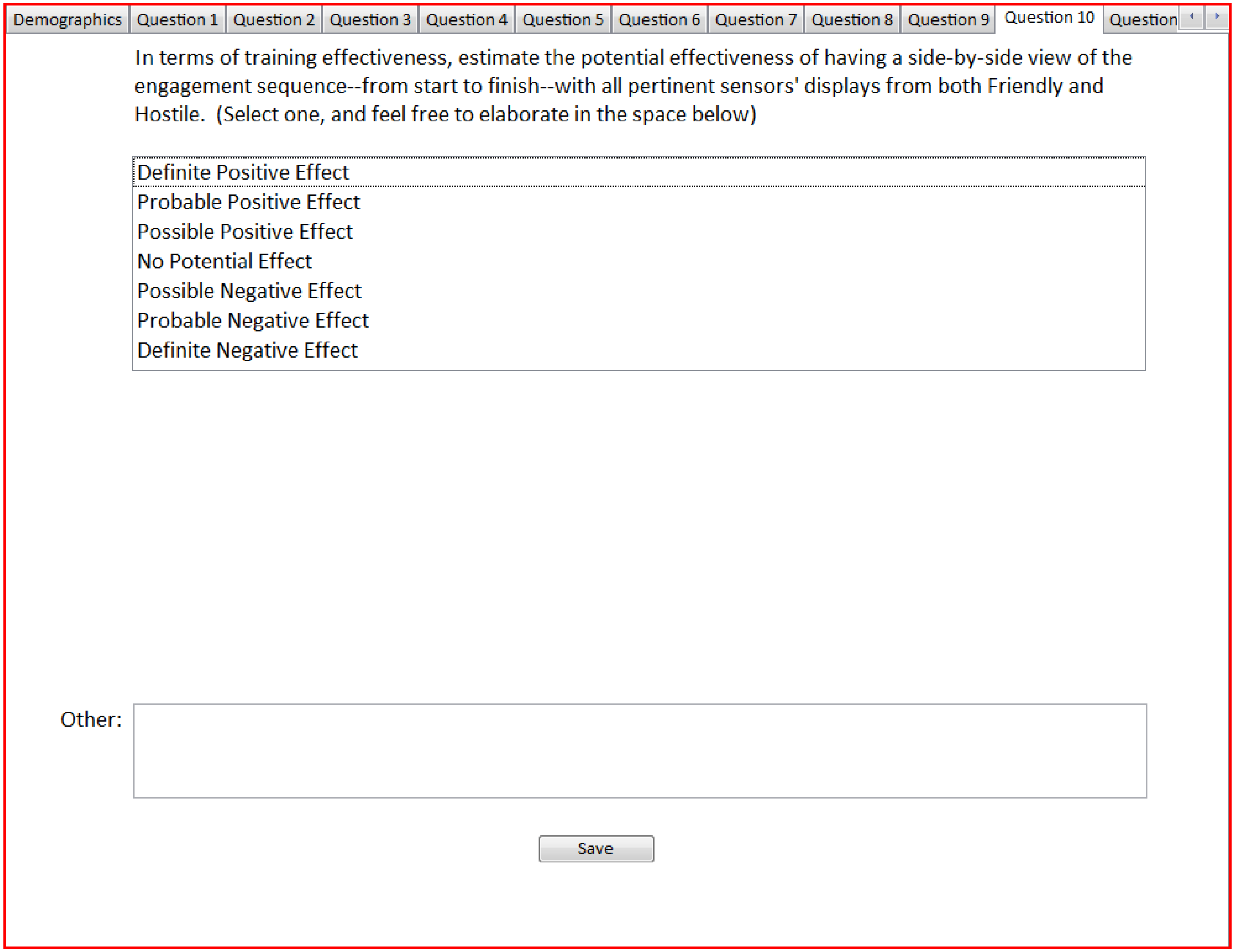


Figure A.10. Question 9



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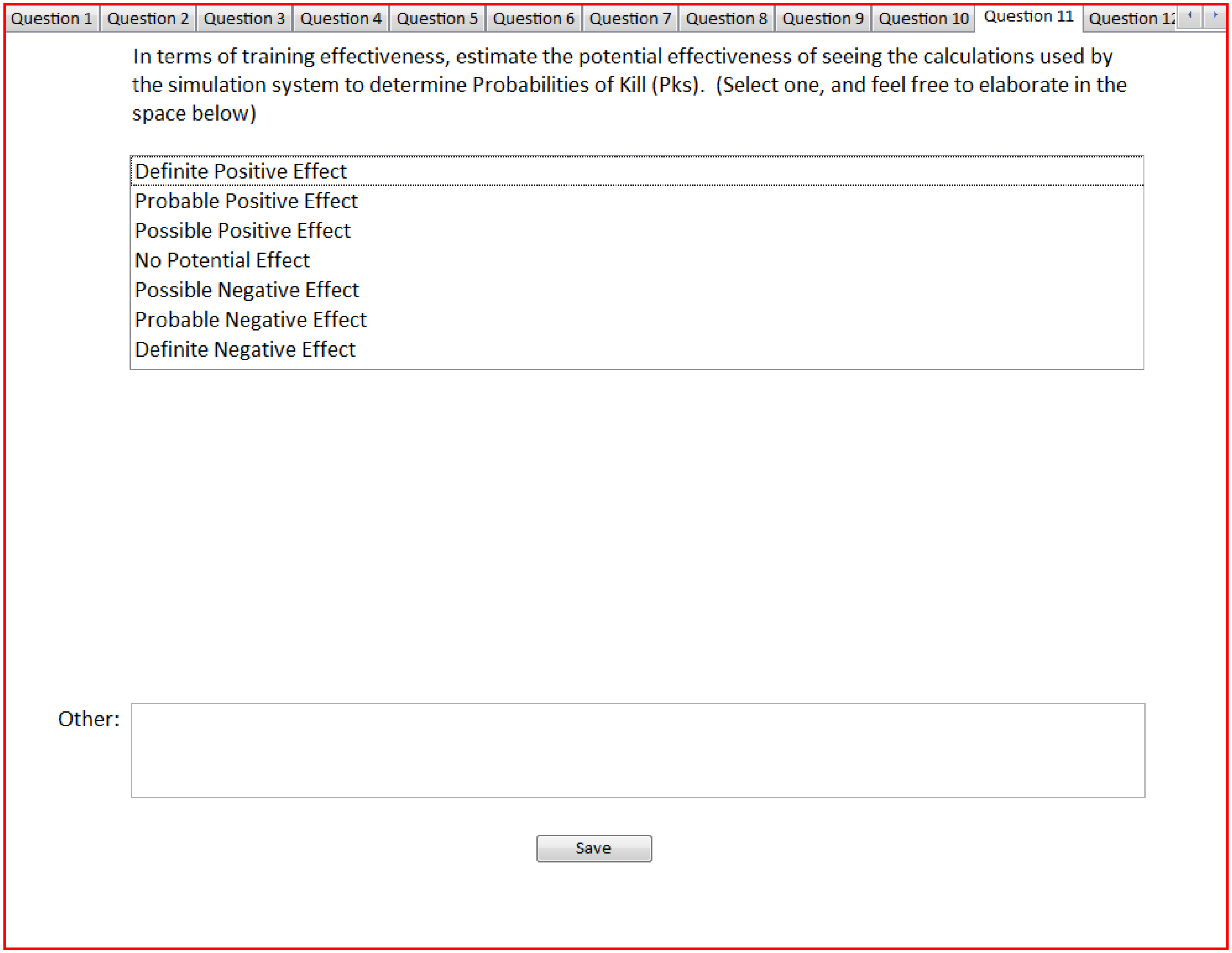


Figure A.12. Question 11

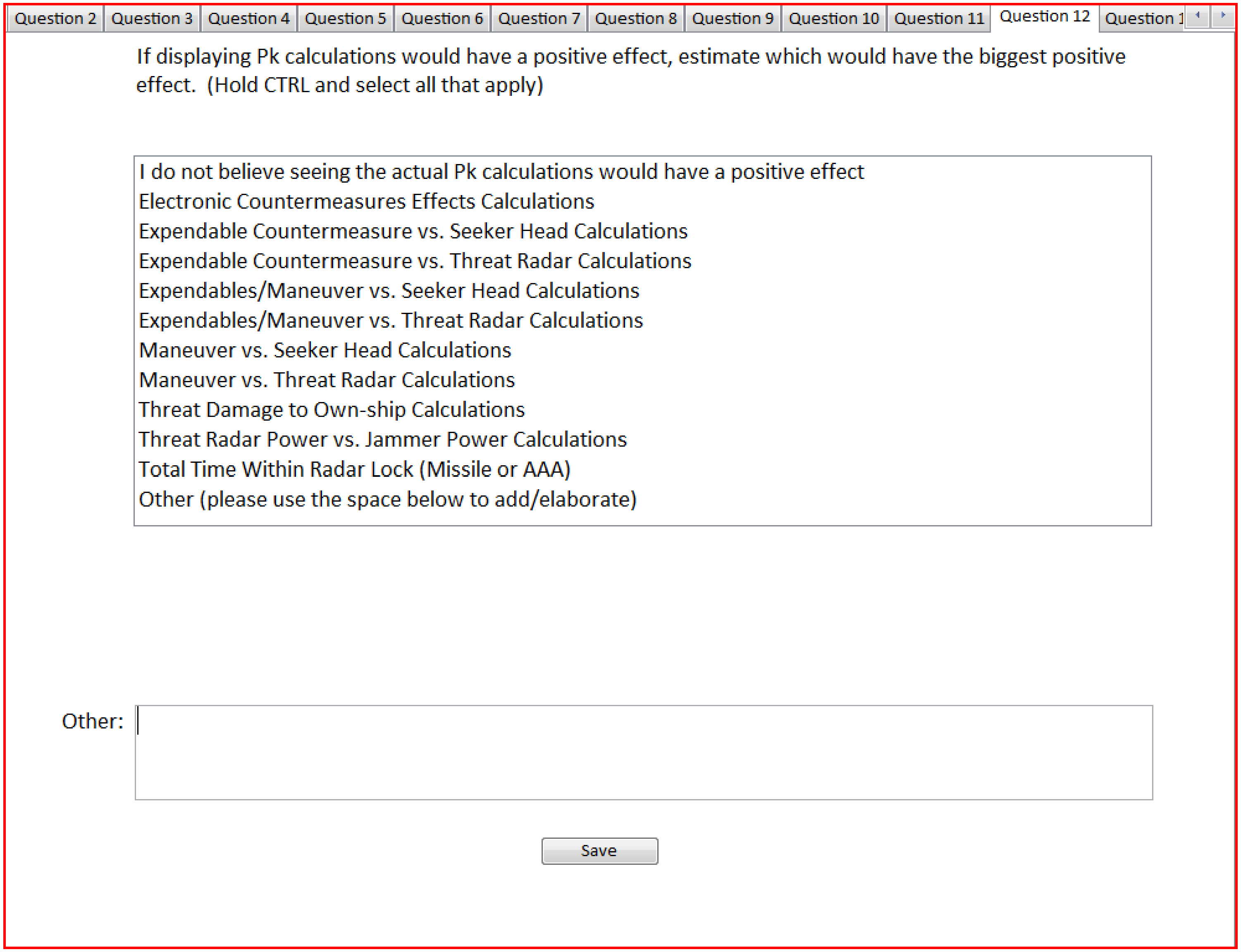


Figure A.13. Question 12

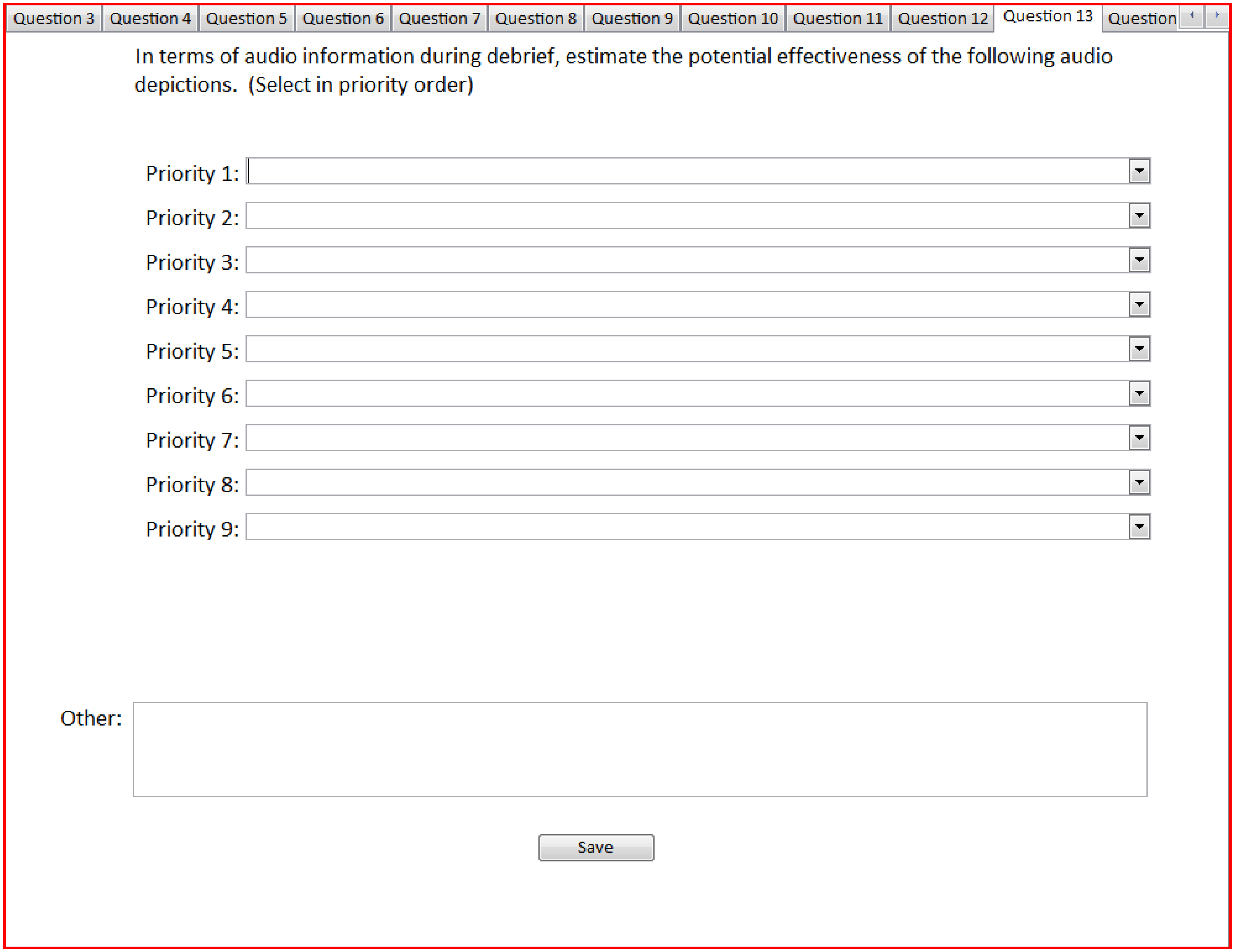


Figure A.14. Question 13

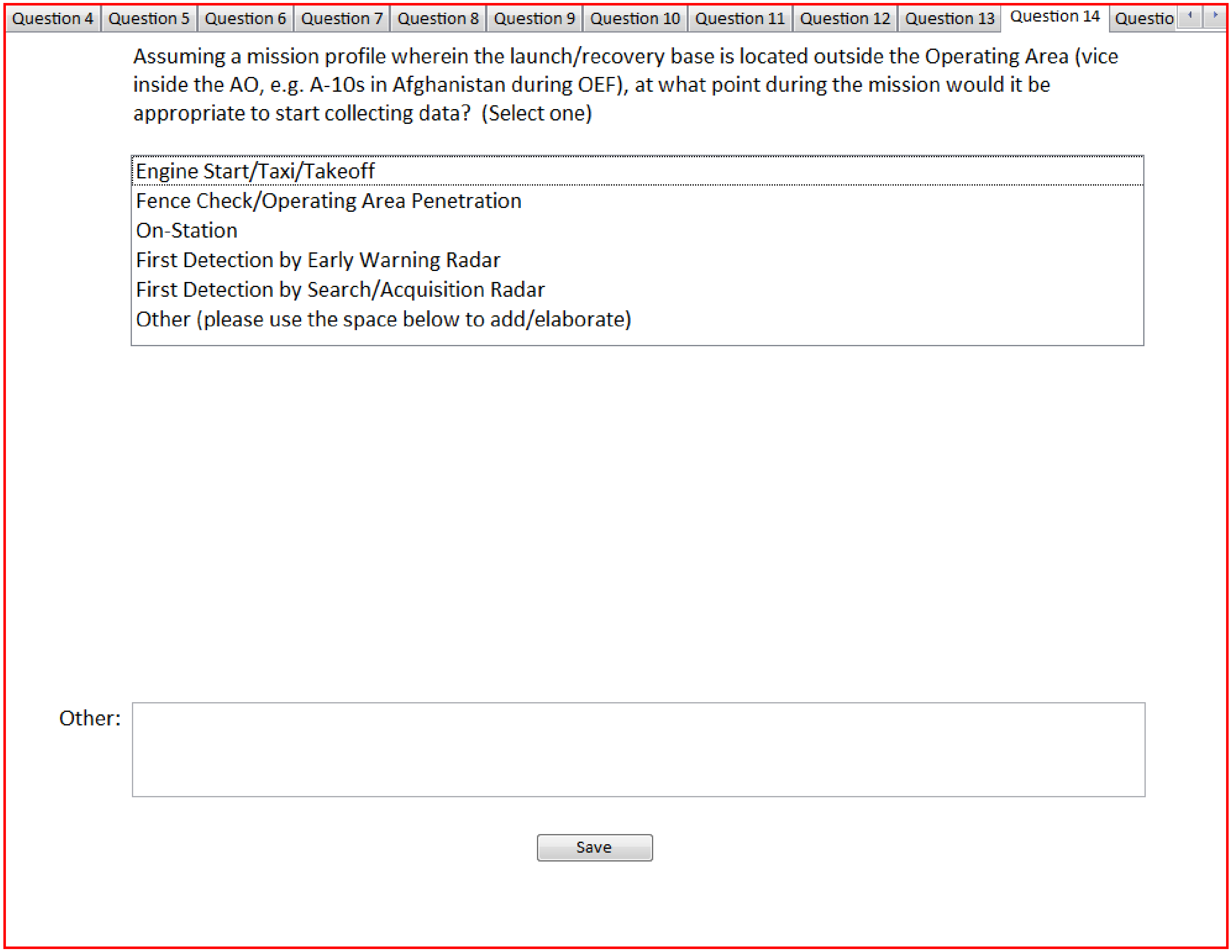


Figure A.15. Question 14

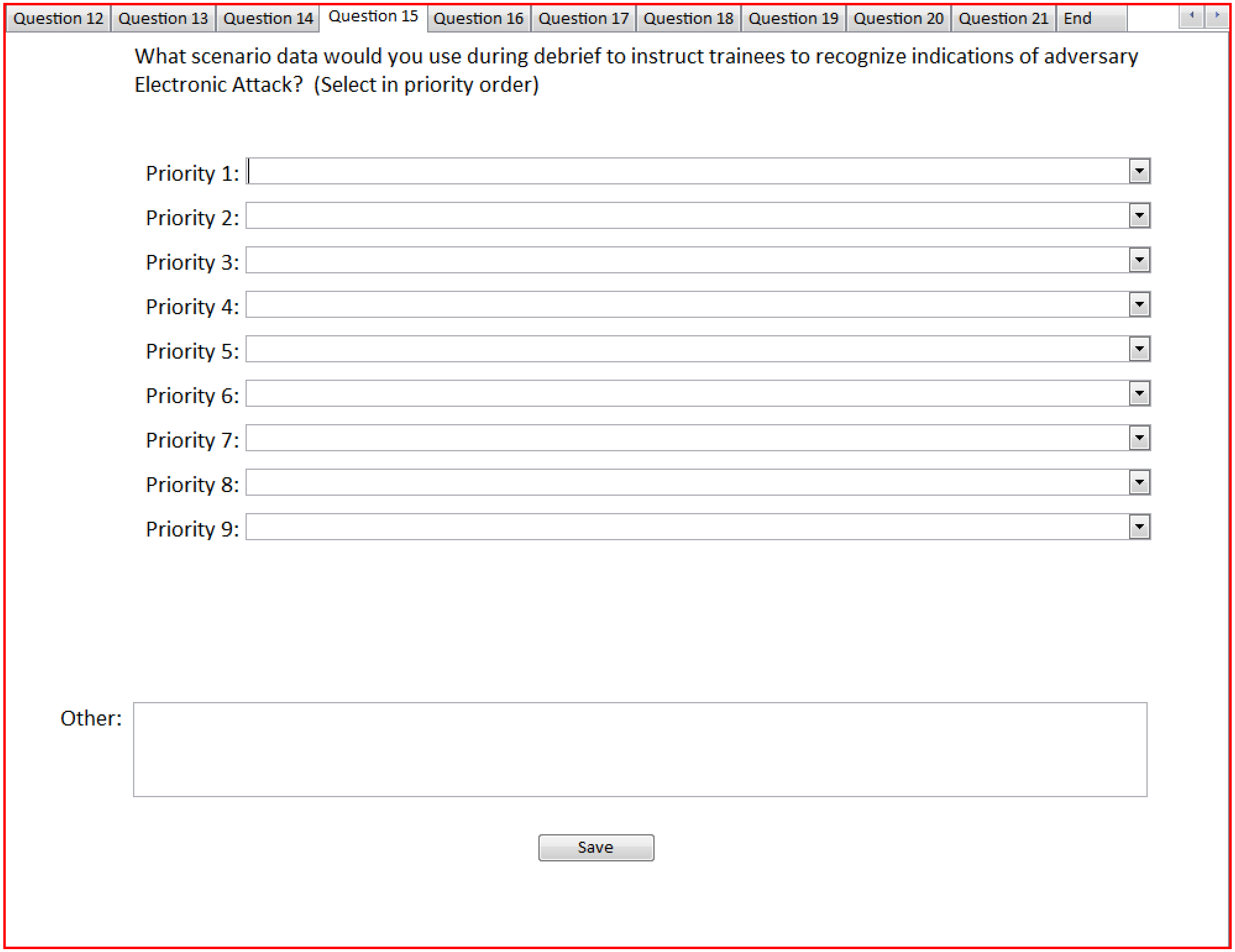


Figure A.16. Question 15

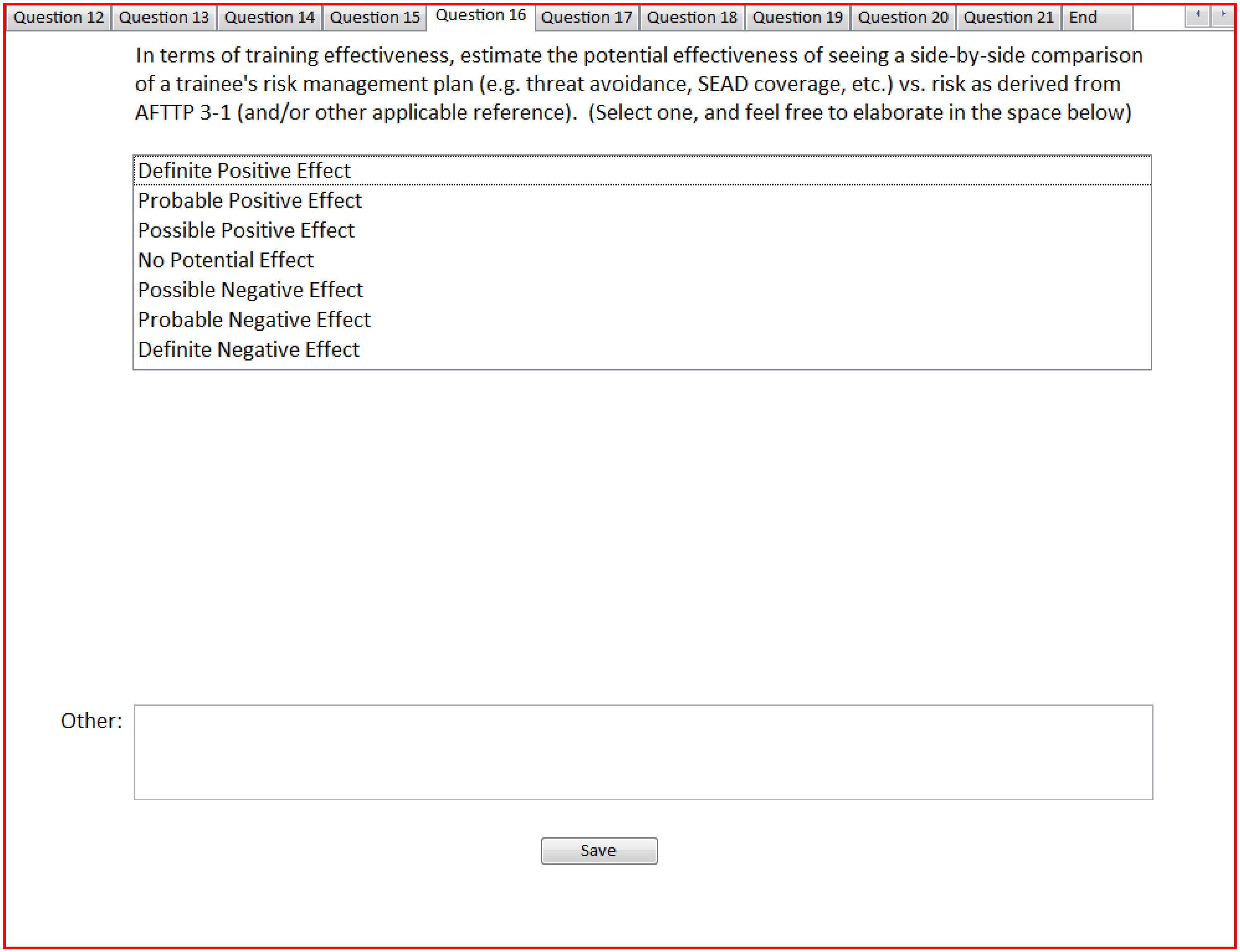


Figure A.17. Question 16

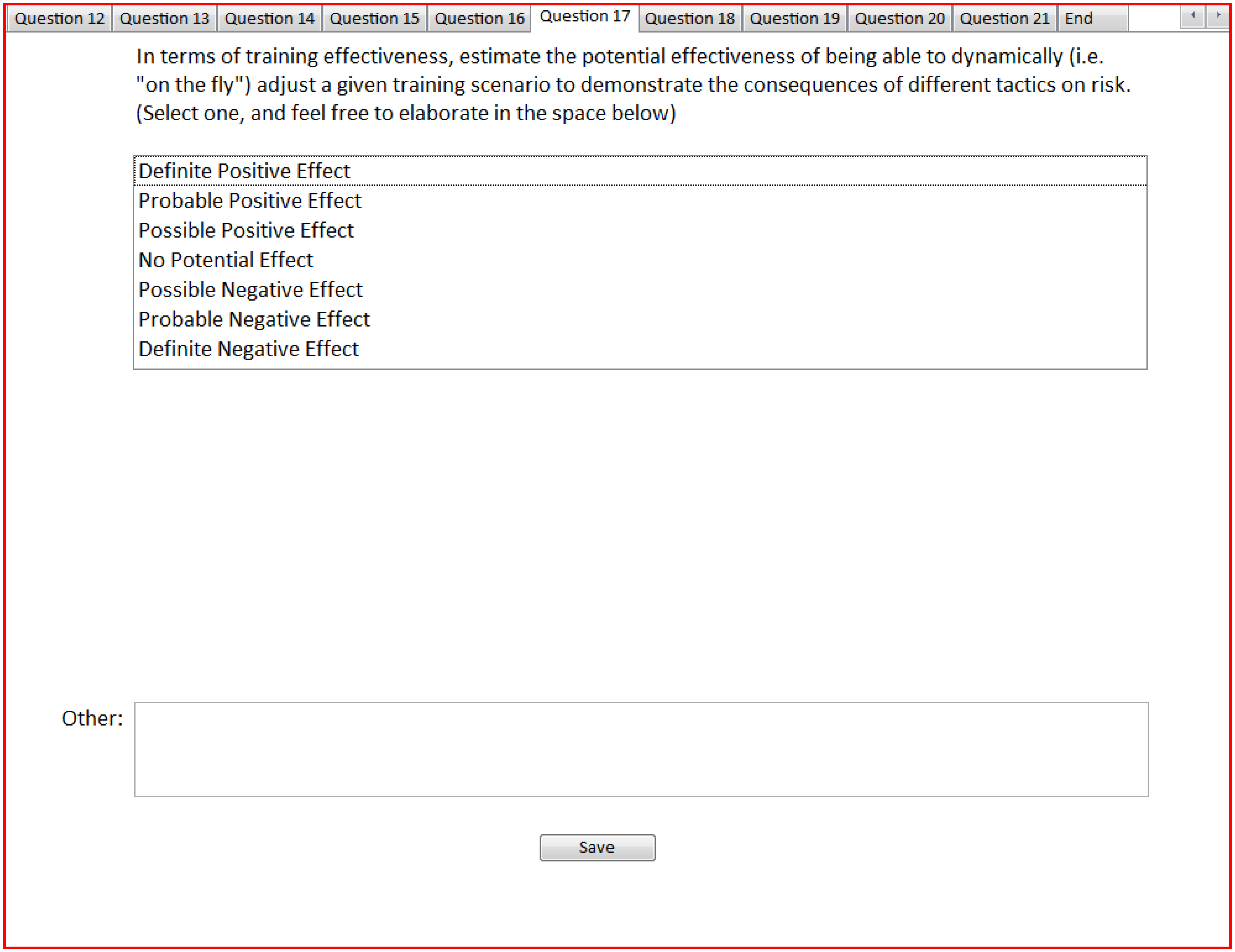


Figure A.18. Question 17

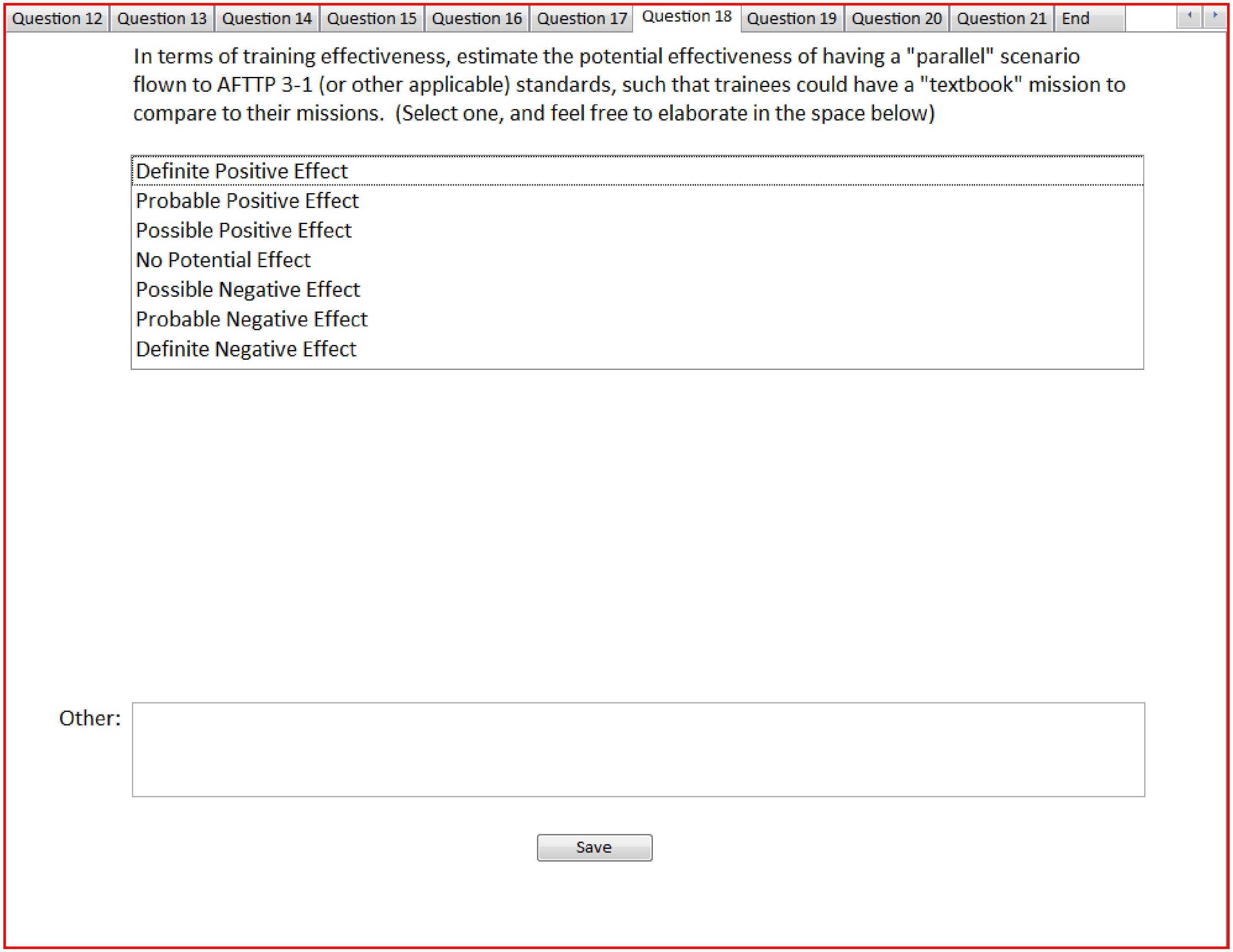


Figure A.19. Question 18

Question 12 | Question 13 | Question 14 | Question 15 | Question 16 | Question 17 | Question 18 | Question 19 | Question 20 | Question 21 | End

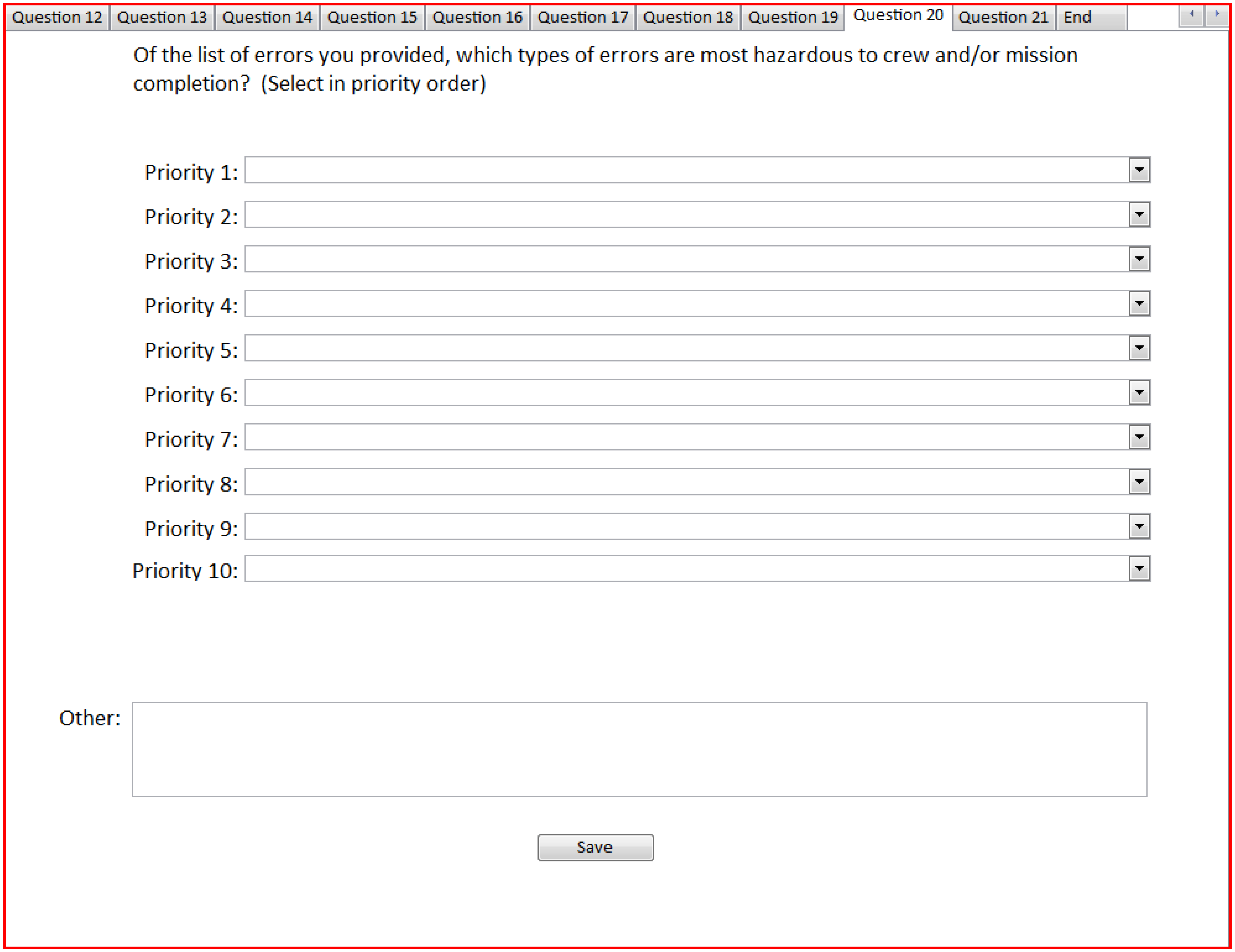
Without consulting Form 8 trend data, what types of errors are most common among trainees in your platform? (Hold CTRL and select all that apply)

- Failure to "Capture" a Threat (as applicable)
- Failure to Geolocate a Threat
- Failure to Recognize Adversary Electronic Attack
- Improper Electronic Jamming Technique/Settings (as applicable)
- Improper Employment of Expendable Countermeasures (as applicable)
- Improper Infrared Jamming Technique/Settings (as applicable)
- "Stepping on" Crew Interphone Comms
- "Stepping on" Radio Comms
- "Switchology"
- Terminology
- Threat Recognition
- Other (please use the space below to add/elaborate)

Other:

Save

Figure A.20. Question 19


Question 12 | Question 13 | Question 14 | Question 15 | Question 16 | Question 17 | Question 18 | Question 19 | Question 20 | Question 21 | End

Of the list of errors you provided, which types of errors are most hazardous to crew and/or mission completion? (Select in priority order)

Priority 1:
Priority 2:
Priority 3:
Priority 4:
Priority 5:
Priority 6:
Priority 7:
Priority 8:
Priority 9:
Priority 10:

Other:

Save

Figure A.21. Question 20

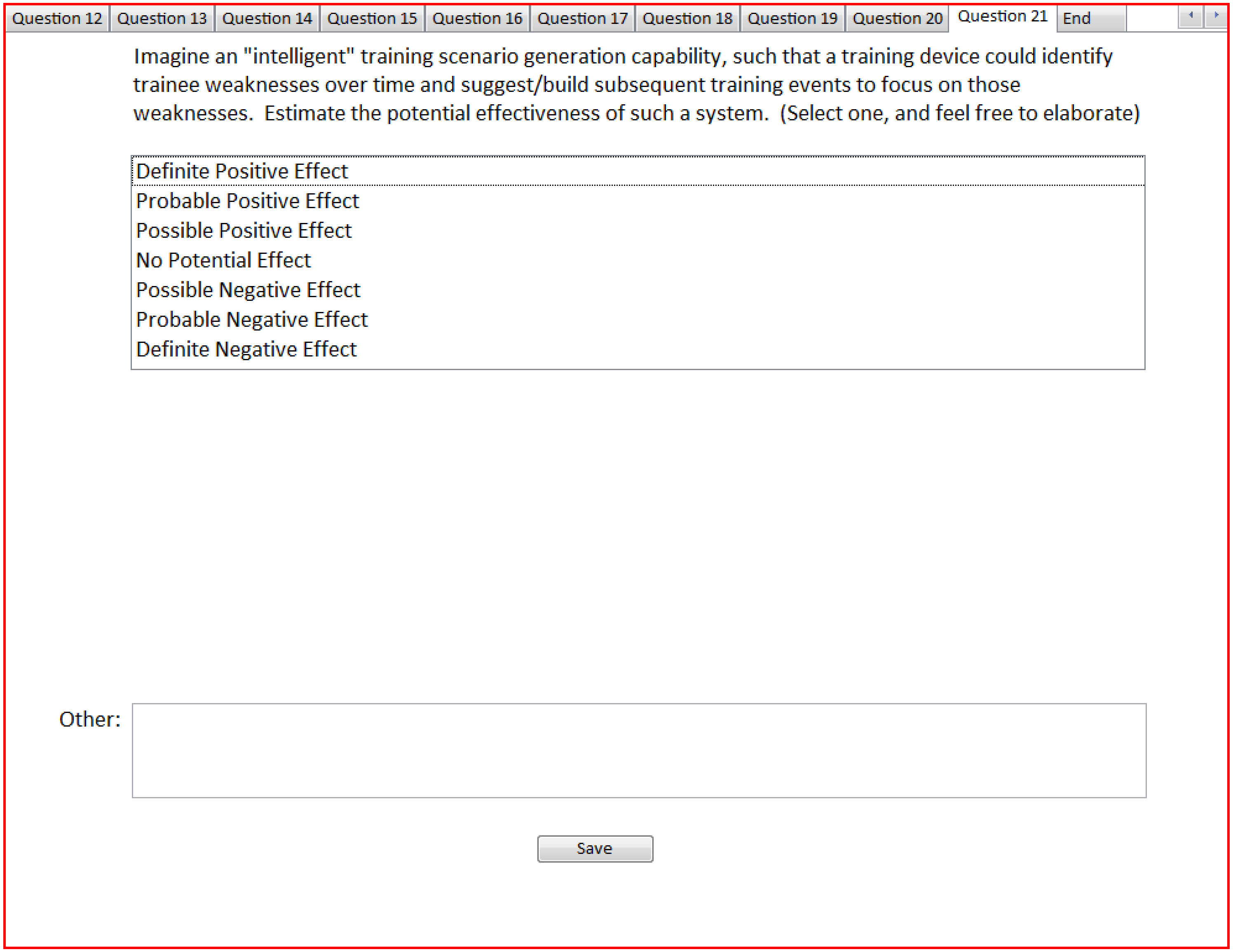


Figure A.22. Question 21

Figure A.23. End

ANNOTATED BIBLIOGRAPHY

Robust Immersive Decision Environments Research (RIDER)

Boydstun, A. S., Patterson, R., Pierce, B., Park, L. M., & Shannan, J. (2010). On the Development of Training Principles for Intuitive Decision Making. Human Factors: *The Journal of the Human Factors and Ergonomics Society, 54*(19), 1713-1716.

Many decisions made in real-world situations involve a form of intuitive pattern recognition. One way to investigate training principles for developing this type of decision making utilizes implicit learning in an immersive environment, where training stimuli are generated by a finite-state algorithm. In the current study, we investigated the effects of manipulating training-sequence length and algorithmic complexity in an immersive implicit-learning paradigm. Results: training-sequence length interacted with algorithmic complexity such that performance was best when training-sequence length was long and the algorithm was simple, and when training-sequence length was short and the algorithm was complex. When training intuitive decision making, training-sequence length should be matched to algorithmic complexity.

Boydstun, A. S., Patterson, R., Pierce, B., Park, L. M., & Tripp, L.M. (2011). Articulatory Suppression Affects Situational Pattern Recognition in Immersive Environments. In *Proceedings of the 10th International Conference on Naturalistic Decision Making*, Orlando, FL, June.

We examined several factors that may affect training for intuitive decision making, namely articulatory suppression, pattern complexity, and stimulus block size. Results: articulatory suppression and pattern complexity impaired decision making, but block size did not. Future work will examine how attention may interact with training for intuitive decision making.

Patterson, R., Fournier, L., Pierce, B. J., Winterbottom, M. D., & Tripp, L. M. (2009). Modeling the Dynamics of Recognition-primed Decision Making. In *Proceedings of the 9th Bi-annual International Conference on Naturalistic Decision Making* (NDM9) 23–26 June 2009 at the British Computer Society, Southampton Street, London, UK.

Two types of decision-making processes have been identified in the literature: an analytical process and an intuitive process. One conceptual model of the latter is the recognition-primed decision (RPD) model. According to this model, decision making in naturalistic contexts entails a situational pattern-recognition process that, if subsequent expectancies are confirmed, leads the decision maker to render a decision to engage in a given course of action. In this paper, we describe a system dynamics model of Klein's RPD framework that focuses upon the dynamics of the decision-making process. The structure of our RPD model is based on a model of a set of laboratory phenomena called conjunction benefits and costs, which was extended to encompass the RPD framework. The results of our simulations suggest that decision priming (a bias toward rendering a given decision based on prior information) is a phenomenon that should occur in many naturalistic settings.

Patterson, R. E., Pierce, B. J., Bell, H. H., Andrews, D., & Winterbottom, M. (2009). Training robust decision making in immersive environments. *Journal of Cognitive Engineering and Decision Making, 3*, 331–361.

We provide a review and analysis of much of the published literature on decision making that is relevant to the design of immersive environments. This review draws from the basic and applied literature in order to provide insight for the design of such synthetic environments. Included in this review are articles and books cited in other works, and articles and books obtained from an Internet search. Issues discussed are (a) an overview of immersive decision environments; (b) dual-process decision making; (c) training robust intuitive decision making; (d) combining analytical and intuitive processing in immersive environments; and (e) concluding remarks. For the development of robust decision making in immersive environments, intuitive reasoning should be emphasized by creating an immersive situation and by providing for the development of automatic processing through implicit learning, with the latter reinforced by explicit thought processes. Considerations of the literature on decision making will provide insight for future design solutions for immersive decision environments.

Patterson, R. E., Pierce, B. J., Bell, H. H., & Klein, G. (2009). Implicit learning, tacit knowledge, expertise development, and naturalistic decision making. *Journal of Cognitive Engineering and Decision Making, 4*(4), 289-303.

Implicit learning involves the largely unconscious learning of dynamic statistical patterns and features. This kind of learning is a ubiquitous, robust phenomenon that likely occurs in most, if not all, tasks in which individuals engage throughout their lives. In this paper, we argue that implicit learning may assist in the acquisition, retention, and transfer of expertise and thus provide a form of *tacit scaffolding* for expertise development. The notion of implicit scaffolding represents a novel and interesting area of future research for the field of naturalistic decision making and naturalistic cognition.

Patterson, R., Pierce, B., Boydstun, A. S., Park, L. M., Shannan, J., & Tripp, L. (2010). *Implicit Learning for Developing Intuitive Decision Making Using Immersive and Flat Displays.* Submitted to The 10th International Conference on Naturalistic Decision Making, May 31-June 3, 2011, Orlando, FL.

Intuition can be a critical asset when making decisions in various situations. In this study, we investigated the acquisition of intuitive decision making through a process called implicit learning. During training, participants passively viewed structured sequences of objects or letter strings presented either on a dynamic terrain seen in perspective view or on a static flat display. We also had participants memorize structured strings of letters presented on a static flat display. Following training, participants were tested for implicit learning by making intuitive judgments of novel structured sequences versus random sequences. Results: implicit learning occurred easily across all conditions and there was no significant performance advantage to one viewing condition over another. This study has implications for the training of intuitive decision making insofar as it demonstrates that cues can be passively and effectively acquired from exposure to different artificial displays.

Patterson, R.E., Pierce, B.J., Boydstun, A.S., Park, L.M., Shannan, J. & Tripp, L.M. (2011). *Implicit Learning for Developing Intuitive Decision Making Using Immersive and Flat Displays*. A poster presented at the 10th International Conference on Naturalistic Decision Making, Orlando, FL, June.

Intuition can be a critical asset when making decisions in various situations. In this study, we investigated the acquisition of intuitive decision making through a process called implicit learning. During training, participants passively viewed a structured sequence of objects or letter strings presented either on a dynamic terrain seen in perspective view or on a static flat display. We also had participants memorize structured strings of letters presented on a static flat display. Following training, participants were tested for implicit learning by making intuitive judgments of novel structured sequences versus random sequences. Results: implicit learning occurred easily across all conditions and there was no significant performance advantage to one viewing condition over another. This study has implications for the training of intuitive decision making insofar as it demonstrates that cues can be passively and effectively acquired from exposure to different artificial displays.

Winterbottom, M., Patterson, R., Fournier, L., Pierce, B. J., Williams, L., & Amann, R. (2009). *Decision Priming in an Air-to-Ground Attack Decision Scenario*. Poster presentation at the NDM9, the 9th International Conference on Naturalistic Decision Making London, UK, June 2009.

Motivation – Validate a System Dynamics model of decision speed for a scenario relevant to an Air Force mission task. Research approach – Extend a decision priming basic research paradigm to a more applied case. Findings/Design – Decision priming was found to occur with more complex stimuli relevant to an air-to-ground target identification scenario. A system dynamics model was developed to predict those results. Research limitations/Implications – While decision delays of approximately 100 milliseconds were found here, it remains to be determined whether decision priming extends to decision processes extending over seconds or minutes. Originality/Value – A temporally-based method of modeling a decision process has been validated for an applied air-to-ground target identification scenario. Many other decision models lack this time component and are therefore of limited use in time-critical situations. Take away message – Tactical situations where information is processed rapidly and sequentially can result in decision priming.

Rehearsal Enabling Simulation Technologies (REST)

Lerman, D. J. (2010). Correct Weather Modeling of non-Standard Days (10F-SIW-004). In *Proceedings of 2010 Fall Simulation Interoperability Workshop* (Fall SIW) SISO. Orlando, FL: SISO.

Most flight simulators compute and fly in a weather environment that matches a standard atmosphere, with the possibility of adding a constant temperature or pressure offset to the standard profile to train non-standard-day flight conditions. The atmosphere on many simulators is computed with the rate of change of pressure altitude against geopotential altitude being 1.0, regardless of any temperature increment added to the temperature profile. Such a model does not account for the density change caused by temperature deviation from standard, disobeys the laws of physics, and is a bad model. This paper describes the effects of such bad modeling on training tasks and presents the math to model the atmosphere correctly.

Sieverding, M. J., Stephens, C. W., & Kent, A. E. (2010). The Emerging DoD Requirement for More Realistic Weather in Flight Simulation. In *Proceedings of the 2010 IMAGE Society Conference*; July 2010; Scottsdale, AZ, USA.

This paper explored the history of the requirements and technical approaches of implementing weather simulation into DoD virtual flight simulators, beginning in the late 1970s and extending to today's devices. It also assesses the new, emerging requirements for mission rehearsal and networked simulation and their potential for deriving the requirement for more realistic weather simulation fidelity. Commercial (Federal Aviation Administration) flight simulator weather modeling requirements will be presented. Authoritative, real-world weather data sources, models, and data types are described. A conceptual design for implementing them in modern flight simulators is presented including visual and sensor displays, as well as its potential impact on improved training. This paper also describes the rules of engagement to incrementally prototype the addition of common, high fidelity weather modeling into high fidelity flight simulators. The prototyping goal is to provide Air Force DMO with a blueprint for achieving improved fidelity and expanded training capability during DMO networked operations. The focus of this paper is on virtual flight simulation applications, but ideas and methods discussed here could be applicable to virtual ground-based simulations as well, especially those that may be networked to virtual flight simulations.

Sieverding, M. J., Rybacki, R. M., & Kent, A. E. (2009). A Method to Compensate for Display System Contrast Ratio Differences in Distributed Simulation (ADA525464). In *Proceedings of the IMAGE 2009 Society*, St. Louis, MO.

A considerable challenge facing distributed virtual simulation is to minimize correlation differences between networked simulations so that humans-in-the-loop perceive and respond to the same stimulus--as they would in the real world. There are many causes or domains of correlation differences, including Appearance, Behavior, and Time. This paper addresses one small component within the Appearance domain of correlation.

Considerable work has been done across the Services to develop methods of reusing environmental/spatial datasets that not only reduce the schedule and cost of database generation, but also achieve greater correlation between differing simulations; however, even if all simulations were to share the same database geometry, textures, colors, and rendering engine, how they would look through the simulations' different display systems can vary dramatically. Distributed simulation may include many different virtual entities that are outfitted with considerably different display systems. Each display system type may have widely varying resolutions, luminance, and contrast ratios, resulting in different perceived scenes even if all systems are using the same rendering engine and spatial database.

This paper presents a method of compensating for widely varying display system contrast ratios, which results in more similarly perceived out-the-window scenes across different simulations. This paper presents a novel algorithmic approach of modifying database colors and intensities. The principal variable within the algorithm is the difference in measured display system contrast ratios between two simulator systems. Contrast ratio test methods, tools, and results are also presented to provide objective and repeatable measures. This paper also describes a method used to remap all pixel colors and

intensities with the adjustment algorithm during run-time, using plug-in shader techniques.

The method described in this paper offers the potential for application across any simulation network where the environment model is built from common, shared datasets, where different types of display systems with widely varying contrast ratios are employed, and where correlated (or at least more similar) perceptions are required.

Entity Modeling and Full Spectrum Threat Simulation

Eidman, C., Boyle, G. H., Lay, M., & Pollak, E. (2010). Physics Based Modeling of a Warhead Detonation using Graphics Processors. (Paper No 10341) In *Proceedings of 2010 Industry/Interservice Training Systems Conference*. Orlando, FL: National Security Industrial Association.

Modeling highly complex entity interactions with high precision is challenging in distributed training simulations. When using existing protocols and standards, most weapons effects are resolved by a probability of a kill or a roll of the dice, reducing accuracy and fair fight. This paper presents the results of a study by the Air Force Research Lab (AFRL) to determine if running physics algorithms using the NVIDIA PhysX SDK with a constructive simulation could more accurately model the damage associated with an aircraft/missile engagement than can be done with the currently used statistics based approach. A statistical approach assumes damage based only on missile proximity at the time of detonation along with a pre-determined probability of kill. This approach typically does not factor the exact aspect, geometry, aircraft material strength, and missile warhead capability at the time of detonation. The study leveraged a Physics-Based Environment Generator (PBEG) running with the Expert Common Interactive Training Environment (XCITE) constructive simulation. The PBEG was programmed to take entity control of the aircraft and missiles from XCITE to determine the level of damage, provide a realistic visualization of the impact and return damage assessment to XCITE. A target aircraft model was constructed rendering multiple sections and facets, each capable of individually sustaining damage. A missile warhead model with a simplified TNT explosive and fragmentation was integrated. The PBEG computed the force of the initial blast shockwave and impact from each high velocity shrapnel piece striking the aircraft on each specific facet. A numerical damage value is assigned for each aircraft part, and damage results are returned to XCITE for training feedback. This approach was shown to increase accuracy in damage assessments over the traditional approach. This paper summarizes the study results and provides recommendations for further investigations using graphics processors for modeling weapons effects.

McCracken, C., Breeden, P., Eidman, C., Walsh, B., Williams, L., Kamrowski, M., Van Ess, G., & Tygret, K. I. (2010). Integration of a Proprietary Missile Server for Assessment of Training Research Effectiveness. In *Proceedings of 2010 Industry/Interservice Training Systems Conference*. Orlando, FL: National Security Industrial Association.

The Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Readiness Research Division, Mesa, AZ (711 HPW/RHA), in cooperation with Raytheon Missile Systems, Tucson, AZ (Raytheon), developed and integrated a full-fidelity advanced medium-range air-to-air missile (AMRAAM) weapon server into a high-fidelity AFRL F-16 flight simulator. The project goals were to bring manufacturer-

proprietary missile fly-out performance into the Air Force Distributed Mission Operations (DMO) environment, to assess simulation effectiveness, and to enhance operator training. Three separate AMRAAM models were evaluated and tested against operational performance metrics to assess capability and potential training impact: the current model employed by the Air Force F-16 Multi-Task Trainer cockpit, the model implemented within the Air Force eXpert Common Immersive Theater Environment (XCITE) synthetic battlespace, and the proprietary AMRAAM Raytheon Simulation (ARS). Multiple parameters were compared, such as maximum range, minimum range, time of flight, maneuvering performance, and target intercept. Testing constraints were overseen and validated by subject matter experts. The results showed that successful integration of a real-time original equipment manufacturer-proprietary missile model with Air Force DMO assets was feasible. Furthermore, fly-out testing results identified specific parameters and situational relationships crucial to improving warfighter instruction during brief and debrief. This performance comparison of currently employed weapons models with the Raytheon AMRAAM model, highlighted the training effectiveness available through the careful integration of manufacturer-proprietary modeling and simulation tools.

Audio Integration/Demonstrations

Knapp, T. D. (2009). *Task Order: 0037 Entity Modeling and Immersive Decision Environments: CDRL A022 Technical Report study/Services Paragraph 4.4 Audio Integrations/Demonstrations*. Mesa AZ: Air Force Research Laboratory, Warfighter Readiness Research Division.

This report detailed the Spatial Audio Integration effort for Task Order 0037 Entity Modeling and Immersive Decision Environments. It describes the approaches considered, problems encountered, their resolutions, and provides implementation details. There is also a summary of current limitations and suggestions for future improvements.

Ultra-High Resolution Deployable Projector Components for Simulation

Geri, G. A., & Williams, L. A. (2011). Photometric and perceptual evaluation of the spatial resolution and laser-speckle properties of a MicroVision ShowWX Pico projector (Warfighter-Contract Technical Memorandum, TO37(2011)-01). Mesa AZ: Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Readiness Research Division.

The spatial and temporal characteristics, as well as the laser-speckle properties, of a MicroVision ShowWX Pico Laser Projector were evaluated using standard techniques. One purpose of the evaluation was to determine if a relatively inexpensive, commercially available laser projector is suitable for use as a flight-simulator cockpit display. More generally, the evaluation was designed to implement and assess techniques for estimating spatial-resolution and speckle-contrast, and to determine whether those techniques may be useful in either future laser-projector evaluations, or as part of a laser-display measurement standard.

Geri, G. A., & Williams, L. A. (2011). Perceptual assessment of laser-speckle contrast. Manuscript submitted to a peer-reviewed displays journal.

A procedure is described for perceptually assessing the effects of laser-speckle on target discrimination in the context of developing a laser-display measurement standard. The perceptual approach avoids the difficulties inherent in assessing speckle contrast photometrically. Size thresholds for triangular test stimuli were obtained using an orientation discrimination task. Data were obtained for both laser and LCD displays, using both a method of constant stimuli and a QUEST procedure. The identification threshold was 29% higher for the laser display. Given that the measured spatial resolutions of the displays were similar, the difference in threshold was attributed to the effects of laser speckle. Laser-speckle size was also estimated as part of the display calibration. For a chosen camera f-number, speckle-size data are necessary to determine the sensor pixel-density required to photometrically estimate speckle contrast, and they may be useful for comparison with the data obtained using the perceptual procedure described here. Mean speckle size was estimated by scaling and normalizing the laser-speckle luminance and then determining the width of the associated autocorrelation function. It is proposed that a laser-display standard be developed based in part upon a comparison of task performance on the laser display to be evaluated and on a standard display.

Lloyd, C. J., Williams L. A., & Pierce, B. J. (2011). A model of the relative effects of key task and display design parameters on training task performance. In *Proceedings of the 2011 IMAGE Society Conference;* June 2011; Scottsdale, AZ, USA.

This paper describes the design and initial validation of a model of the relative effects of key task and display design parameters on training task performance. The display system design parameters include pixel hold time, pixel pitch, luminance, contrast, and noise. The task and observer parameters include target size and range, angular velocity (of the image), target contrast, and observer capability (e.g., acuity).

This model was developed as part of the Immersive Display Evaluation and Assessment Study (IDEAS) program for the USAF. The model was designed to be used by display system acquisition professionals who must develop defensible display system requirements that are based on the ability of the display system to support the training planned for the system. The model was also designed for those display systems professionals in the supplier community who wish to steer their product designs in the direction of maximum utility to the USAF.

The initial validation results indicate the model accurately summarizes the findings from several published evaluations that employed tasks generally representative of flight simulation training. The model was then used to make specific predictions of the effects of 220 combinations of four parameters (hold time, velocity, pitch, and luminance) on the range at which pilots could reliably identify fighter sized aircraft. A formal evaluation of the effects of these parameters was conducted and the results of this evaluation are compared with the predictions. A high correlation between model predictions and the results of this evaluation was obtained.

Lloyd, C. J., Joralmon, D. Q., Amann, R. T., Tai, C. F., Williams L. A., & Pierce, B. J. (2011). Relative effects of five display design variables on aircraft identification range in daylight. In *Proceedings of the 2011 IMAGE Society Conference*; June 2011; Scottsdale, AZ, USA.

This paper summarizes the findings from two human factors evaluations conducted as part of the Immersive Display Evaluation and Assessment Study (IDEAS) program. For both evaluations experienced USAF F-16 pilots discriminated and positively identified distant fighter-sized aircraft. On each trial the ownship rapidly approached a pair of aircraft, one “friend” and one “foe,” and the observers designated the foe as quickly and accurately as they could.

The first evaluation focused on variables expected to be primary determinants of motion-induced blurring (e.g., hold time and angular velocity) for modern display systems. The second evaluation filled out the data set required to validate a more complete model of the design variables expected to mediate task performance for very high resolution display systems. Across the two evaluations, task performance was measured as a function of 420 combinations of five practical display system design variables including: pixel hold time, angular velocity of the image, pixel pitch (resolution), display contrast, and display luminance.

Prior to conducting the evaluations a computational model was prepared and used to make quantitative predictions of the effects of these design variables. The correlation between the model predictions and the results of the first evaluation was high (e.g., $R2 > 0.75$, $p < 0.001$, 109 df). After tuning three parameters in the model to the data the correlation increased significantly ($R2 = 0.973$, $p < 0.001$, 106 df).

A significant benefit provided by the model is the quantification of the interactions among the design variables. Thus, the model is useful for examining the impact of design trades among the variables that affect task performance.

Lloyd, C. J. (2011). Towards a decision support system for generating display requirements for simulation training. In *Proceedings of 2011 Industry/Interservice Training Systems Conference*. Orlando, FL: National Security Industrial Association.

The complexity of the acquisition process for training display systems has increased in recent years due to the rapid changes in the technologies underlying these systems. For two decades prior to this complexity surge, the relationship between the military customer and their suppliers was more stable: most suppliers provided custom image generators and >90% of display systems used mature CRT projectors. Display system customers fell into the habit of essentially adopting current product specifications as the “requirements” for new systems, a practical strategy given these systems had worked well for many years. The recent introductions of multiple new technologies (e.g., PC Igs, COTS projectors, automated display calibration systems, and practical stereoscopic displays) have substantially disrupted the traditional relationships between customer and supplier. New suppliers have entered the system integration market as the incumbents have struggled to keep up with technology changes. Customers can no longer rely on relatively stable product capabilities or long term supplier relationships to ensure their next training display system meets the needs of their users.

In response to these trends, the Immersive Display Evaluation and Assessment Study (IDEAS) program was initiated in the summer of 2010. The long term goal of this program is to produce a decision support system (DSS) that will enable (1) Air Force acquisition professionals to rapidly generate defensible display system requirements given a set of training task requirements, (2) suppliers to develop new visual systems and

prepare proposals, and (3) aid certifiers to measure performance. Some overarching goals for the DSS include:

Usable by persons who understand the training need but are not experts in current display technology

- Produces defensible requirements based on task performance data and previously validated models
- Identify the data and models that underlie each recommendation
- Allows high level design trades to be made during the requirements generation process
- Produces the specific text and levels for selected display system requirements
- Provides the approved measurement procedure for each requirement
- Employs an architecture that allows updating the data and models as technologies evolve

Development and validation of the first model/data to be incorporated into the DSS began in the fall of 2010. This work is summarized in DTIC technical reports and two papers presented at IMAGE 2011. The present paper provides a brief overview of the development and validation of the model and focuses primarily on how the model and DSS might be used by stakeholders.

The paper and presentation will describe the general capabilities of the DSS and will provide concrete examples of:

- Generation of selected display requirements from the F-16 MTC training task list
- Use of the DSS to make source selection decisions
- Generation of measurement procedures
- Use of the DSS by a supplier for product development planning

A primary goal of this paper is to solicit inputs from stakeholders prior to and concurrently with the development of the system.

Lloyd, C. J., Joralmon, D. Q., Amann, R. T., Tai, C. F., Morgan W., Geri, G. A., Williams L. A., & Pierce, B. J. (2011). *Effects of hold time, angular velocity, pitch, and luminance on simulated aircraft identification range.* AFRL technical report, to be submitted to Defense Technical Information Service (DTIC).

This paper summarizes the findings from the first of two human factors evaluations conducted as part of the Immersive Display Evaluation and Assessment Study (IDEAS) program. In this evaluation experienced USAF F-16 pilots discriminated and positively identified distant fighter-sized aircraft. On each trial the ownship rapidly approached a pair of aircraft, one ―friend" and one ―foe," and the observers designated the foe as quickly and accurately as they could.

This evaluation focused on the effects of three variables expected to be primary determinants of motion-induced blurring; hold time, angular velocity of the image, and

pixel pitch. An external motion blur reduction shutter was used to systematically manipulate hold time causing luminance to co-vary with hold time. Thus, a fourth independent variable, luminance, was included in the evaluation so that its effect could be estimated independently of the hold time variable.

Prior to conducting the evaluation, a computational model was prepared and used to make quantitative predictions of the effects of these design variables. The correlation between the model predictions and the results of this evaluation was high (e.g., $R2 > 0.75$, $p < 0.001$, 109 df). After tuning three parameters in the model to the data, the correlation increased significantly ($R2 = 0.973$, $p < 0.001$, 106 df).

A significant benefit provided by the model is the quantification of the interactions among the design variables. Thus, the model is useful for examining the impact of design trades among the variables that affect task performance.

A summary of this evaluation was published at the IMAGE 2011 conference. The present report contains more of the details of the evaluation, the instructions to observers, and a table of the mean response data for the 220 experimental conditions.

Lloyd, C. J., Joralmon, D. Q., Amann, R. T., Tai, C. F., Morgan W., Williams L. A., & Pierce, B. J. (2011). *Effects of luminance, contrast, hold time, angular velocity, and pitch, on simulated aircraft identification range.* AFRL technical report, to be submitted to Defense Technical Information Service (DTIC).

This paper summarizes the findings from the second of two human factors evaluations conducted as part of the Immersive Display Evaluation and Assessment Study (IDEAS) program. In this evaluation experienced USAF F-16 pilots discriminated and positively identified distant fighter-sized aircraft. On each trial the ownship rapidly approached a pair of aircraft, one “friend” and one “foe,” and the observers designated the foe as quickly and accurately as they could.

The first evaluation focused on the variables expected to be primary determinants of motion-induced blurring (e.g., hold time and angular velocity) for sample-and-hold display systems. This second evaluation filled out the data set required to validate a more complete model of the design variables expected to mediate task performance for very high resolution display systems. In this evaluation, task performance was measured as a function of 200 combinations of five practical display system design variables including: display luminance, display contrast, pixel hold time, angular velocity of the image, and pixel pitch (resolution).

Prior to conducting the evaluation, a computational model was prepared and used to make quantitative predictions of the effects of these design variables. The correlation between the model predictions and the results of this evaluation was high (e.g., $R2 = 0.911$, $p < 0.001$, 199 df). The model parameters have not yet been tuned to the data collected in this evaluation.

A significant benefit provided by the model is the quantification of the interactions among the design variables. Thus, the model is useful for examining the impact of design trades among the variables that affect task performance.

A summary of this evaluation was published at the IMAGE 2011 conference. The present report contains more of the details of the evaluation and a table of the mean response data for the 200 experimental conditions.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

2D	Two-Dimensional
3D	Three Dimensional
6DoF	6-degrees of freedom
ACE	Advanced Command Environments
AFCD	Air Force Common Dataset
AFRL	Air Force Research Laboratory
ASC	Aeronautical Systems Center
ATC	Air Traffic Control
CAF	Combat Air Force
CGF	Computer Generated Force
CM	Configuration Management
CRADA	Cooperative Research and Development Agreement
DE	Directed Energy
DIS	Distributed Interactive Simulation
DISNET	Distributed Interactive Simulation Network
DMO	Distributed Mission Operations
DSS	Decision Support System
DTED	Digital Terrain Elevation Data
EDT	Employment, Doctrine, and Tactics
EMTS	Entity Modeling and Full Spectrum Threat Simulation
ESLP	Evans and Sutherland Laser Projector
ESRI	Environmental Systems Research Institute
FOB	Forward Operating Base
GARS	Global Area Reference System
GeoTIFF	Geospatial Tagged Imagery File Format
GUI	Graphical User Interface
HLA	High Level Architecture
HUD	Head Up Display
IDEAS	Immersive Display Evaluation and Assessment Study
IFF	Identification Friend or Foe
IG	Image Generator
I/ITSEC	Interservice/Industry Training, Simulation and Education Conference
IOS	Instructor Operator Station
IR	Infrared

IRB	Institutional Research Board
JTAC	Joint Terminal Attack Controller
LVC	Live-Virtual-Constructive
M&S	Modeling and Simulation
MEMS	Micro-Electrical-Mechanical Systems
MGRS	Military Grid Reference System
MIT	Massachusetts Institute of Technology
MTC	Mission Training Center
NAVAIDS	Navigational Aid Systems
NGTS	Next Generation Threat System
NIU	Network Interface Unit
PBEG	Physics-Based Environment Generator
PDU	Protocol Data Unit
REST	Rehearsal Enabling Simulation Technologies
RFTE	Radio Frequency Threat Environment
RIDER	Robust Immersive Decision Environments Research
RPD	Recognition-Primed Decision
SE	Synthetic Environment
SME	Subject Matter Expert
TACAN	Tactical Air Navigation Systems
TRS	Training and Rehearsal System
UN	United Nations
USAF	United States Air Force
UTM	Universal Transverse Mercator
WRDS	Western Ranges Dataset
WRSTP	Warfighter Readiness Science & Technology Program
XCITE	eXpert Common Immersive Theater Environments